1 Introduction:

Getting More Women into Science and Engineering—Knowledge Issues

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INNOVATIONS SURROUNDING WOMEN and gender have rocked science and technology in the past three decades. Who, for example, could have predicted that the chief scientist at NASA would be a woman (France A. Córdova, now president of Purdue University, and an author in this volume)? Or who would have thought that geneticists would dethrone the "master gene" model—that conceptualized mammalian sex as determined by a single master gene on the Y chromosome—and put in its place an account that emphasizes interactions between the testis and ovary factors (see Richardson this volume)? Or who would have imagined that an artificial knee would be designed with nineteen unique aspects to meet the distinctive skeletal and load-bearing needs of females?

In my lifetime, the situation for intellectual women in the United States has improved dramatically. We can measure these changes partially through images. Anyone growing up in American consumer culture understands the power of images. Images project messages about hopes and dreams, mien and demeanor, about who should be a scientist and what science is all about. We have seen some interesting changes in who is imagined to be a scientist in our society. Historically, when prompted to "draw a scientist," 98 percent of the students drew males (Kahle 1987, see Figure 1.1). By the 1990s, that had declined to 70 percent with some 16 percent of the scientists drawn being

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clearly female and another 14 percent ambiguous with respect to sex (Figure 1.2). In the 1990s, a remarkable 96 percent of the scientists continued to be depicted as Caucasian despite the prominence of Asians in science (Rahm and Charbonneau 1997).

We can also see gendered innovations in the content of science, in this case, in understandings of human evolution. Most of us grew up with an image of human evolution as the "evolution of man" (Figure 1.3). Evolutionary theory presented males as actively and aggressively driving forward human evolution. As Charles Darwin stated, only something he called the "equal transmission of characters" allowed traits selected for in males to be transmitted to females (Hrdy 1999).

In 1993, a much-heralded new image was produced to correct this picture. In that year the American Museum of Natural History in New York opened

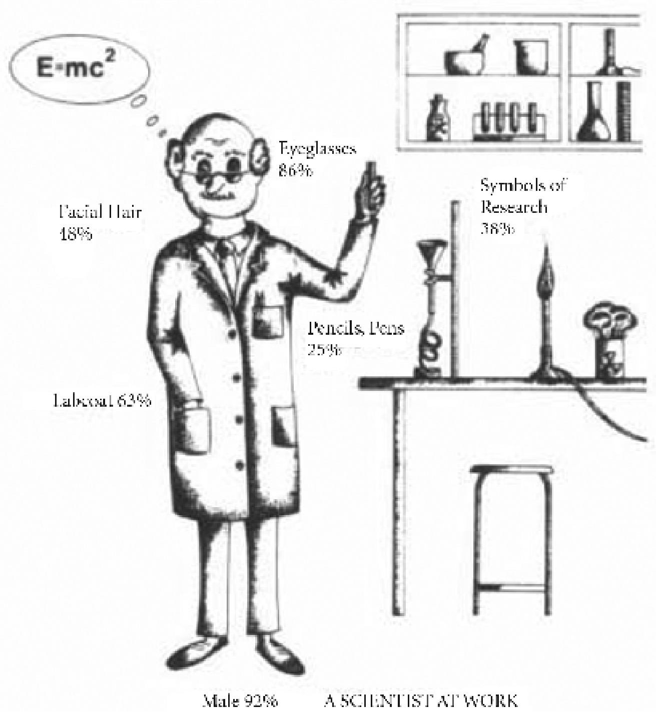

FIGURE 1.1 Results of "Draw-a-Scientist" Test. Most school-aged children draw a male. Source: Jane Butler Kahle in *Gender Issues in Science Education* (Curtin University of Technology, 1987).

FIGURE 1.2 A woman naturalist working outdoors with glasses but without a lab coat. Source: Rahm and Charbonneau, *American Journal of Physics* (August 1997, 65(8), pp. 774–778), “Woman scientist,” on p. 776 (Fig.1 (E)).

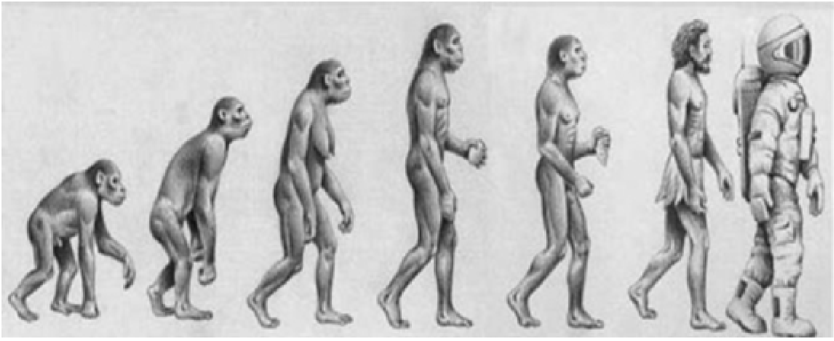

FIGURE 1.3 The evolution of man.

its new “Human Biology and Evolution” exhibit featuring this reconstruction of early humans from the 3.5 million-year-old footprints preserved in volcanic ash near Laetoli (Figure 1.4). This diorama clearly gives woman a place in human evolution, and although the assumptions captured in this image have changed dramatically since the 1960s, the process is still incomplete. The humans embodying the footprints are portrayed as a robust male towering over his smaller female consort, his arm positioned to protect and reassure her. We simply do not know, however, the sex or relationship of the two individuals who made these impressions—footprints cannot be sexed. These early humans might have been a large male and his much smaller mate, but

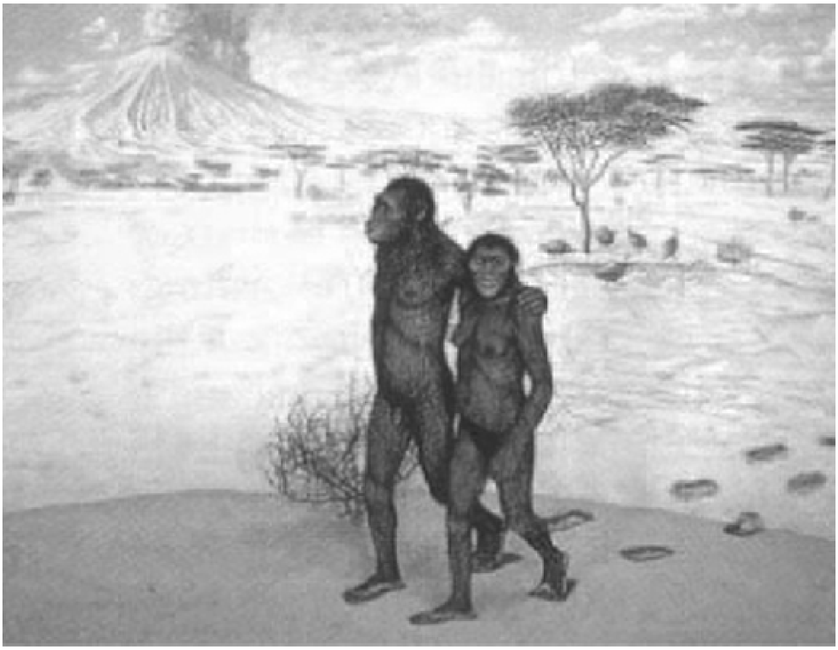

FIGURE 1.4 Reconstruction of the early humans presumed to have made the Laetoli footprints, as shown at the American Museum of Natural History in New York—fact or fantasy? Source: Image # 2A19270 © American Museum of Natural History.

they might also have been a parent comforting his or her adolescent offspring, or just two friends fleeing the volcano together.

The purpose of this volume is to analyze changes of this sort—gendered innovations—in science and engineering. By gendered innovations I mean transformations in the personnel, cultures, and content of science and engineering brought about by efforts to remove gender bias from these fields. As documented in this volume, understanding and removing gender bias has brought new insights to specific sciences and fields of engineering. I want to emphasize from the beginning that gender analysis is not attached to the X or Y chromosome—that, if properly trained, most researchers successfully master its theory and practice. Gender analysis, when applied rigorously and creatively, has the potential to enhance human knowledge and technical systems by opening them to new perspectives, new questions, and new missions.

To understand better how this works, I set out three distinct levels of analysis (see also Schiebinger 1999 and 2003):

1. Fix the Number of Women: Participation of *Women* in Science and Engineering. The first level focuses on increasing the participation of women in science and engineering. This level of analysis treats the history and sociology of women's engagement in scientific institutions. Who are the great women scientists? What are their achievements? What is the experience of women in university, industrial, and governmental laboratories? Programs aimed at increasing the number of women in science and engineering (rightly or wrongly) attempt to "fix the women"—that is, to make them more competitive—by increasing funding to women's research, teaching them how to negotiate for salary, or, more generally, how to succeed in a man's world.

2. Fix the Institutions: Gender in the *Cultures* of Science and Engineering. A culture is more than institutions, legal regulations, or a series of degrees or certifications. It consists in the unspoken assumptions and values of its members. Despite claims to objectivity and value neutrality, the sciences have identifiable cultures whose customs and folkways have developed over time. Many of these customs developed historically in the absence of women and, as I have argued elsewhere, also in opposition to their participation (Schiebinger 1989). How have the cultures of science and engineering, where success requires at least some mastery of the rituals of day-to-day conformity, codes governing language, styles of interactions, modes of dress, hierarchies of values and practices, been formed by their predominantly male practitioners? Programs that attempt to increase women's participation taking this approach work to "fix the institutions." The National Science Foundation's (NSF) current ADVANCE grants, for example, attempt to transform university cultures. These efforts range from understanding subtle gender biases in hiring practices, for example, to restructuring the academic work/life balance by offering parental leave, stopping the tenure clock, and the like.

3. Fix the Knowledge: Gender in the *Results* of Science and Engineering. Scholars have emphasized the consequences of exclusion for women, but what have been the consequences of this exclusion for human knowledge more generally? At this third level, authors focus on "fixing the knowledge." A number of chapters in this volume explore how gender analysis, when turned to science and engineering, profoundly enhances human knowledge. This is a vital issue to address today, and here we provide examples of how gender analysis has sparked creativity by opening new questions for future research. This work is crucial to our efforts to recruit and retain women. Importantly, programs, such as those at the National Institutes of Health (NIH—see below) have linked the project of increasing the number of women in the medical profession to that of reconceptualizing medical research.

WHILE IT IS USEFUL to distinguish issues at three analytical levels, these perspectives are obviously closely tied to one another. Emerging evidence reveals that women will *not* become equal participants in science and engineering until we have fully investigated and solved the knowledge problem. Disciplines are somewhat arbitrary ways of cutting knowledge. We need to be open to the possibility that human knowledge—what we know, what we value, what we consider important—may change dramatically as women become full partners. Science is about critical thinking, exploration, and travel into unknown worlds. We have much to gain by embarking on this voyage.

To set the stage for what follows, let me place the chapters within the analytics I distinguish.

Participation of Women in Science and Engineering

Many people believe in progress. They believe that things are gradually getting better for women. How many times have I been patted on the head and told, "Just wait, dear, and women will move to the top." One point I want to make is that progress for women is not a fact of nature but the result of careful interventions on the part of individuals, institutions, and governmental agencies.

Let me offer just three quick examples of how we cannot just sit back and wait for things to right themselves. Opportunities for women result from larger social and economic restructurings in a society in addition to changes in university cultures. As is widely known, women were excluded from modern universities from their founding in the twelfth century until the end of the nineteenth century. In this sense, women are real newcomers to university research labs. Women embarked on modern careers in science after the women's movements of the 1870s and 1880s propelled them into universities. As women gradually gained admittance to graduate schools—by the twentieth century a prerequisite for serious work in science—they began flooding into PhD programs in all fields. By the 1920s their numbers were at a historic high in the United States, with women earning 14 percent of doctorates in the physical and biological sciences. Between 1930 and 1960, however, the proportion of women PhDs plunged as a result of the rise of fascism in Europe, the Cold War, and McCarthyism in the United States. Shockingly, women did not regain their 1920s levels of participation in academic science until the 1970s (Rossiter 1982; Zuckerman et al. 1991).

A second example shows even more clearly how social structures influence women's opportunities in science and engineering. In the seventeenth century in Germany, 14 percent of all astronomers were women. Today the percentage of women astronomers in Germany is around 5 percent (counting all lecturers and professors at German universities). How was this possible? The very different economic and social structure of life in early modern Germany gave women an opportunity to participate in ways not available to them today. As I have argued elsewhere, astronomy in this period was organized along guild lines. Guilds were social and economic organizations through which most goods were produced and services provided. Guild production took place in the household. In astronomical families, the labor of husband and wife did not divide along modern lines: he was not fully professional, working in an observatory outside the home; she was not fully a housewife, confined to hearth and home. Nor were they independent professionals, each holding a chair of astronomy. Instead, they worked as a team and on common problems. Many took turns observing so that their observations, often made in their own attics, followed night after night without interruption. At other times they observed together, dividing the work so that they could make observations that a single person could not make accurately. Guild traditions within science allowed women, such as Maria Margaretha Winkelmann, to strengthen the empirical base of science (Schiebinger 1989).

A final example from the Massachusetts Institute of Technology (MIT) reveals that traditional departmental hiring processes do not always identify exceptional female candidates. MIT was successful at increasing its women faculty when its president and provost collaborated with department heads and women faculty committees to implement novel hiring procedures. These successes in both the Schools of Science and Engineering were pushed forward as a response to the disastrous 1996 reports on women faculty at MIT. Forward-looking deans, Robert Birgeneau in Science and Thomas Magnanti in Engineering, were able to help hiring committees find qualified women when encouraged to. These women hired in the School of Science achieved tenure at the same rate as their male colleagues and a slightly higher level of professional success than the men as measured by election to the prestigious National Academy of Sciences and the like (Hopkins 2006).

I am not arguing that we adopt any particular social order or university policy. My point is that the overall organization of society—the way we organize households, child care, economic production, roads, social services, universities, schools, and governments—all have an impact on women's opportunities in science. Foundational questioning and reorganization of society and science will be required to make women truly equal. Studies show that professional women currently do more domestic labor than professional men. At the same time these women are expected to compete on an equal footing with men (some of whom have stay-at-home partners) for jobs and salaries (Williams 2000). We need to end the social welfare state in the home for men (especially those with professional partners). Men need to assume their fair share of the pleasures and pains of organizing and caring for domestic spaces.

Since the Sputnik years, the United States and Western European countries have attempted to increase the participation of their populations in science—women as well as men. In the United States, this led to foundational legislation, including the Equal Pay Act of 1963, Equal Employment Opportunity Act, and Title IX of 1972, designed to foster equality for women. In her chapter in this volume, Sue Rosser documents how the NSF, beginning in the 1980s, has attempted to improve the numbers of women in science and engineering by jump-starting their careers with extra research monies and the like. In a later chapter, France Córdova summarizes similar efforts undertaken by the National Academies (the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine). Founded in 1991, the Academies' Committee on Women in Science and Engineering (CWSE) has worked with Congress and universities to develop policy aimed at assisting women's careers. (I should note that I attempted to include a chapter on innovations in Europe in this volume but European Union lawyers would not approve its publication.)

These initiatives—both on the part of the government and universities—have focused narrowly on getting more women in the door. As important as these measures are, they alone are not enough. In recent years, the NSF, CWSE, and numerous universities have moved to the second level in my stepped analysis and begun working toward understanding and helping to correct the underlying causes of inequality.

Gender in the Cultures of Science and Engineering

There have been two fundamental approaches in efforts nationwide to gain equality for women in the academy: liberal feminism and difference feminism. Oddly enough, many people in the United States and elsewhere practice feminist virtues, while at the same time shying away from calling themselves "feminists." I would venture to say that the vast majority of Americans are feminists, at least liberal feminists—that is to say that they support equality and professional opportunities for women—though most would not call themselves feminists. It is important to recognize that what is "feminist" in one time and place becomes business as usual in another. It is a curious phenomenon that when feminist practices or points of view become widely accepted in science and engineering, or in the culture more generally, they are no longer seen as "feminist," but as "just" or simply "true." The result is that the term *feminist* continues to refer to people and policies on the radical cutting edge. In her chapter on genetic models of sex determination, Sarah Richardson presents a classic example of how feminism disappears when its principles are mainstreamed into science. The fact that researchers may be unaware of the sources of new insights does not make those sources any less real—but it does serve to keep feminism on the sidelines.

Authors in this volume will use the term *feminist* to refer to efforts to bring about institutional and social change leading to greater equality for women because one needs to discuss this process and this is the appropriate English term for it. One thing to emphasize is that there are many feminisms. Sue Rosser (2005) has distinguished at least ten different feminist approaches to science and technology. Here I want to emphasize only two fundamental feminist perspectives: liberal and difference feminism. Although these two approaches differ, they are not mutually exclusive, nor does the one supersede the other. In some instances liberal feminism is the best approach—it is certainly the best understood in the United States. At other times the insights offered by what I call *difference feminism* lead best to reform.

Liberal feminism has been the major form of feminism in the United States and much of Western Europe since the English feminist Mary Wollstonecraft's vigorous call for equality in her 1792 *Vindication of the Rights of Woman*.

Liberal feminism has supported well the participation of women in the professions. It has informed major legislation guaranteeing women's rights, as well as equal education, pay, and opportunity. It is the theory underlying government and university interventions seeking greater equality for women at level one in my analysis. Liberal feminism has made such inroads that most people think of these issues in terms of "fairness" rather than of "feminism" (Rosser and Córdova, this volume).

While liberal feminism has supported reforms for women in the professions, it has also led to problems. Liberals generally see women as the in-principle equals of men and strive to provide women the skills and opportunities to make it in a man's world; they attempt to "fix the women" by making them more competitive. In the attempt to extend the rights of "man" to women, liberals have tended to ignore *sexual* and *gender* differences, or to deny them altogether. Liberal feminists tend to see sameness and assimilation as the only grounds for equality, and this often requires that women be like men. Only women have babies, but birthing is supposed to take place exclusively on weekends and holidays, not to disrupt the rhythm of working life. Consequently, women have tended to hide pregnancy, or even to "schedule" babies. One biologist, for example, had labor induced on a three-day weekend so she could attend a student's thesis defense the following Monday. Within a liberal frame of mind, women feel that they must compete with men on men's terms.

In the early 1980s, feminists began developing what is broadly called "difference feminism," embracing three basic tenets. First and foremost, difference feminism diverged from liberalism in emphasizing difference, not sameness, between men and women. This strand of feminism argued secondly that in order for women to become equal in science or engineering, changes are needed not just in women but, more importantly, in the culture of classrooms, research labs, and science and engineering departments. The value of difference feminism has been to bring to light cultural differences between men and women and to show how these have worked against women in the professions, including the professions of science and engineering. Culture is about communities' unspoken rules. It is about unwritten codes governing behavior, language, styles of interactions, modes of dress, hierarchies of values, and practices.

Discrimination against women is no longer overt—it's not the 1960s when jobs for professors of chemistry, for example, could read "no women need apply." Discrimination against women now is more often invisible and subtle. Even though it is subtle, unconscious cultural biases can work against women. Most people these days would tell you that they are all for women becoming equal and taking positions of leadership. Yet many professors, deans, provosts, and presidents, while well-meaning, are also often unaware of how unconscious cultural biases work against women and their success in academic culture. These gender biases are not intentional—these are not planned discriminations against women—but they are nonetheless very real and make it more difficult for women than for men to succeed within universities and laboratories as they exist today (Valian 1998; Committee on Maximizing the Potential of Women in Academic Science and Engineering et al. 2006).

Let me enumerate several examples to illustrate this point. Women are often held to different standards than are men. Research has shown that women needed 2.5 more publications than men to be awarded postdoctoral fellowships by the Medical Research Council in Sweden (Wennerås and Wold 1997). In the United States, evaluators also tend to score men higher simply because they are men. In a now well-known experiment, a group of social psychologists gave the *very same* article to evaluators with a variety of fictitious names: John T. McKay (a man), Joan T. McKay (a woman), J. T. McKay (supposedly sex-neutral), and Chris T. McKay (ambiguous with regard to sex). The articles were identical in all ways except for the name of the supposed author. Evaluators—both men and women—rated the article attributed to John superior to the article attributed to Joan. They preferred the ambiguous "J. T." to Joan, but ranked John higher than J. T. Readers scored the article significantly lower when they thought "Chris" was a woman (Goldberg 1968; Paludi and Strayer 1985).

This preference for males carries over into hiring decisions. Another study showed that faculty members—again both men and women—are more likely to evaluate a dossier more positively when that dossier was attributed to a man rather than to a woman (Steinpreis et al. 1999). These practices are reinforced by letters of recommendation that differ significantly with respect to sex. Letters for male applicants tend to be longer and more substantial; they also more often portray men as researchers and professionals and women as students and teachers (Trix and Psenka 2003). Gender bias follows women up the ladder. In our culture women are expected to exude politeness in both speech and manner; they are expected to nod and smile to express attentiveness (Hochschild 1989). Professional women who cannot always engage in these behaviors may be viewed as hostile or unfriendly. Consequently women are often "damned if they do" and "damned if they don't" when entering the ranks of leaders (Eagly and Karau 2002).

In addition to fine-tuning academic culture, we need to fundamentally restructure aspects of it, which is a more complex proposition. Historically, universities—like professional life in general—have been organized around the assumption that professors are male heads of households. Now that women are professionals too nothing systematic has been done to reform the professions to allow for the reproduction of life. This has direct consequences for professional women who remain largely in charge of domestic labor and child care. Women who wish to succeed in science and engineering often remain single and childless. In the United States, tenured women scientists are twice as likely to be single as their male counterparts. In addition, many women simply drop out of science and engineering when they decide to marry or have a family. Many professional women who also take charge of domestic life *do* compete successfully with men who have stay-at-home wives—but at a price to themselves and often their health (Schiebinger 1999; Mason and Goulden 2002). Here is where the example I provided above from guild life becomes interesting. It indicates the level of social restructuring that will be required if the United States is serious about increasing the numbers of women in science and engineering. Hours will need to be shortened, quality child and elder care need to be available and affordable, along with flextime even for high-powered careers and reentry programs for people who have taken time off for personal reasons.

Another asymmetry in professional culture that affects women's careers more than men's is the growing phenomenon of the dual-career academic couple. It is an interesting fact that women more often than men are partnered with professionals. Among heterosexual couples in the United States (and we don't have equivalent studies of same-sex couples), women tend to practice "hypergamy," that is to say, they tend to marry men of higher (or at least not lower) status than their own. This is due partly to the fact that women's social status was determined historically through marriage, while men's was more often determined by inheritance or success in a profession. Consequently, professional women today are disproportionately partnered with professionals compared to men. To make matters worse, academics tend to couple within the same discipline. While only 7 percent of the members of the American Physical Society are women, for example, an astonishing 44 percent of them are married to other physicists. An additional 24 percent are married to some other type of scientist. A remarkable 70 percent of women mathematicians and 46 percent of women chemists are married to men in their own fields. Although universities have begun to reform hiring practices to accommodate some, usually outstanding, dual-career couples, being a partner in such a couple makes it difficult to follow the logic of a career and seize opportunities as they arise (Blondin 1990; McNeil and Sher 1998; Wolf-Wendel et al. 2003; Clayman Institute 2006).

Solutions to the problems of gender asymmetries in the cultures of science and engineering are not simple. Cultural change cannot be legislated; academic culture must be understood and altered through the same consensual process that gave it rise. In recent years, the NSF has launched its ADVANCE program recognizing that the "lack of women's participation at the senior level of academe is often a systemic consequence of academic culture" (as reported by Rosser, this volume). Since 2001 NSF has made five-year grants of up to $3.75 million each to nineteen leading universities across the country to study and transform their ways of doing business. Several of these universities have been particularly successful and two are highlighted in this volume. Sue Rosser reports on initiatives at Georgia Tech to remove subtle gender and racial biases in promotion and tenure decisions. Danielle LaVaque-Manty and Abigail Stewart report on the University of Michigan's successful Strategies and Tactics for Recruiting to Improve Diversity and Excellence (STRIDE) program aimed at reforming hiring practices. Michigan increased its hires in the natural sciences and engineering from women averaging 14 percent of the hires pre-STRIDE to around 35 percent post-STRIDE. In this program distinguished senior science and engineering faculty (five men and four women) were "taught" the specifics of gender bias in hiring practices. This STRIDE committee, whose members were compensated by the university for their time, then prepared a handbook that they used to teach members of hiring committees about evaluating bias and other barriers women face in academia. The brilliance of this program is that these senior faculty are all regular members of departments (they are not consultants who come, often create a backlash, and then disappear). By virtue of the fact that these newly trained gender experts are permanent and respected members of science and engineering faculties, knowledge concerning subtle gender bias cascades through those departments. The academic climate of opinion changes gradually as these faculty go about their day-to-day work at the university.

Other initiatives are also under way. In spring 2005, the Government Accounting Office issued a report prepared for Senators Ron Wyden and Barbara Boxer on how Title IX of the United States Education Amendments of 1972 can be harnessed to increase the number of women and minorities in science (U.S. Government Accountability Office 2004). In spring 2006, Stanford's

Clayman Institute for Gender Research held a meeting to strategize how universities might collaborate nationally to move forward programs in this area. Stanford's Clayman Institute has also launched a multiyear study of dual-career academic couples at leading United States research universities. The goal of this and other studies is to transform the way universities do business and grow academic cultures where women, too, can flourish.

Much is being done at the level of gender in the cultures of science and engineering. Much remains to be accomplished. The recent joint statement on gender equity by the presidents of the nine leading United States universities is welcome in this regard ("University Leaders" 2005). These prestigious institutions continue to work together, sharing best practices and specific initiatives, to remove barriers that limit women's full participation in academic life. Their goal is to create conditions in which all faculty are allowed to achieve at the highest level. These types of efforts are crucial, but they will not be successful unless changes come also at a third level: gender in human knowledge and technology.

Gender in the Results of Science and Engineering

Many people may be willing to concede that women have not been given a fair shake, that social attitudes and scientific institutions need to be reformed. They may also be willing to concede that women are excluded in subtle and often invisible ways. They stop short, however, of analyzing how gendered practices and ideologies have structured knowledge. Does the exclusion of women from the sciences and engineering have consequences that go beyond the issues discussed above? Is the question of gender in science and engineering merely one of institutions and opportunities for women, or does it impact the content of these disciplines as well?

Since the Enlightenment, science has stirred hearts and minds with its promise of a "neutral" and privileged vantage point, above and beyond the rough and tumble of political life. Men and women alike have responded to the lure of science: "the promise of touching the world at its innermost being, a touching made possible by the power of pure thought" (Keller 1992). The power of Western science—its methods, techniques, and epistemologies—is celebrated for producing objective and universal knowledge, transcending cultural restraints. With respect to gender, race, and much else, however, science is not value neutral. Scholars have begun to document how gender inequalities, built into the institutions of science, have influenced the knowledge issuing from those institutions (Gero and Conkey 1991; Harding 1991; Schiebinger 1993, 1999, 2003, 2004; Rosser 1994; Spanier 1995; Hager 1997).

A number of chapters in this volume provide exemplary case studies of how removing gender bias can open science and engineering to new theoretical perspectives and research questions. Before we turn to these examples, let me say a word first about difference feminism in this regard. Difference feminism can be helpful in aiding our understanding of how the cultures of institutions must change in order to accommodate women. But difference feminism can be especially *unhelpful* when applied to knowledge. In the 1980s much difference feminism promoted the notion that women had a lot to contribute to science and engineering because, it was said, women hold different values and think differently. It is important to understand, however, that gender characteristics often attributed to women—cooperation, caring, cultivating a feeling for the organism, or whatever it may be—date back to the eighteenth century and were produced in efforts to keep women out of science and the public sphere (Schiebinger 1989). In romanticizing traditional femininity, difference feminism does little to overturn conventional stereotypes of men and women. Women's historically wrought gender differences cannot serve as an epistemological base for new theories and practices in the sciences. There is no "female style" or "women's ways of knowing" ready to be plugged in at the laboratory bench or clinical bedside. Women—as females of the species—do not do science differently; science should not necessarily be "for women, by women, about women." Difference feminism or standpoint theory, as it is sometimes called, can tend to exclude men from understanding how gender operates. Everyone—men and women—must contribute to reforming knowledge.

But this is not to say that gender bias has not had a huge impact on science and engineering: ignoring these biases is to ignore possible sources of error in the past and also the future. It must be emphasized that gender analysis requires rigorous training; there is no recipe that can simply be plugged into the design of a research project. It must also be emphasized that the tools for gender analysis are as diverse as the variants of feminism and of science or engineering. As with any set of tools, new ones will be fashioned and others discarded as circumstances change. Some transfer easily from science to science, others do not. The brilliance of their implementation depends, as with other research methods, on the creativity of the research team. Training in gender analysis is something that must become part of undergraduate and graduate education in the sciences and engineering. Gender analysis acts as yet another experimental control to heighten critical rigor.

Perhaps the best way to understand how gender analysis works is to study examples where this type of analysis has brought important critiques of bias and developed new perspectives or insights in particular areas.

The best example of how gender analysis has changed science comes from the biomedical sciences where a revolution in women's health research has taken place in the United States since the 1960s. As is now well known, before 1993 drugs were typically tested on men and the results generalized to women. As a result, adverse reactions to drugs occur twice as often in women as in men. Until recently, for example, little was known about the effects of aspirin on heart disease in women, yet women of an appropriate age were encouraged to take an aspirin each day (Rosser 1994; Ruzek et al. 1997).

Importantly, these biases were not redressed through the promised self-correcting mechanisms of scientific research. It seems fairly evident that studying drugs in nonrepresentative populations is simply bad science. Yet correction in this case required political intervention at the highest levels of government. In the 1990s, the NIH founded the Office of Research on Women's Health. This office has two missions: (1) to increase the number of women in the medical profession and, importantly, (2) to reconceptualize medical research. In addition, NIH launched the Women's Health Initiative, the largest single study ever undertaken by NIH (Haseltine and Jacobson 1997). As Bernadine Healy, former head of NIH who oversaw these innovations, put it: "let's face it, the way to get scientists to move into a certain area is to fund that area" (Gura 1995). In 1993 a federal law was passed that women must be included in clinical drug trials, and that cost could not be used as a justification for excluding them.

Second to medicine, biology has been a field much transformed by gender analysis. These transformations have not been driven by government policies or granting agencies but by a growing awareness that removing gender bias can improve the science. Because biology deals with sex and gender, and because biology has been open to women (45 percent of PhDs are currently women), biologists have moved more swiftly than others to remove glaring cultural bias. In addition, textbooks have been revised to include the contributions of women scientists and to remove outmoded and sexist metaphors (of heroic sperm capturing demure and passive eggs, for example).

In this volume, Sarah Richardson tells the powerful story of how gender analysis contributed to an overhaul of theories of sex determinism that guide research in reproductive biology. In the 1980s, geneticists championed a "master gene" model of sex determination (the notion that a single gene controls the development of an entire organ system). Further, they saw the Y chromosome as a trigger that (in tandem with sex hormones) explained sexual dimorphism. In this model, males determine sex; females develop by default. Richardson documents how the development of gender analysis in the 1990s along with an active women's movement in both society and science dethroned the master gene and put in its place a model of sex determination that takes into account the interactions of testis and ovarian factors in the co-production of sexual dimorphism. Today biologists see both male and female pathways as highly complex and interactive.

Richardson goes on to make the important point that although geneticists gradually became sensitive to gender issues, they did not credit feminism for the many insights it provided. It is a common phenomenon that when gender criticism becomes one among many tools of analysis in a research program, its feminist roots are ignored. As noted above, what is feminist in one time and place becomes business as usual, simply "good science," when it enters the mainstream.

Archaeologists, by contrast, tend to employ gender analysis more consciously, and Margaret Conkey opens her chapter with a taxonomy of feminist approaches to the study of prehistory. To discuss these approaches in concrete terms she analyzes Olga Soffer's work with Venus figurines of the Upper Paleolithic found in the modern-day Czech Republic. These Venus figurines point up certain difficulties confronting students of prehistoric societies. First, nature has a preservation bias: Durable goods (stone tools, metals, and the like) preserve well, but fiber-based technologies (weaving or plaiting) succumb quickly to the ravages of time. Second, archaeologists often shoehorn material evidence from prehistoric societies into modern-day assumptions about sexual divisions of labor and the like. Conkey shows that because Soffer was willing to question basic background assumptions and go at her finds with new questions and perspectives, she discovered new forms of evidence for the existence of textiles.

What Soffer uncovered, with the assistance of her colleague James Adovasio, was that these Venus figures contained evidence of lost technologies: coiling, plaiting, twining, and the like. In short, Soffer revealed the earliest evidence of weaving in human history. The significance of this work for gendered innovations in science is two-fold. First, Soffer lifted these Venus figurines out of the realm of biology (their heavy breasts and hips are often seen as fertility symbols). Further, she provided evidence of fiber technologies that archaeologists have previously undervalued because today these technologies are associated with females. Soffer's work significantly expands and corrects our view of prehistoric people and their cultures.

Paleoanthropologist Lori Hager finds that similar unexamined assumptions have contributed to "sexism in sexing" skeletons—the prized "finds" for human origins research. When viewed uncritically, fossils tend to tell us more about the assumptions of modern-day researchers than about our human ancestors. Working with partial and fragmented skeletons, paleoanthropologists have in the past tended to sex large and robust individuals male and diminutive specimens female. This bias is itself so robust that a whopping 90 percent of Australian Aboriginal skeletal remains have been sexed male—well over the 50 percent expected sex ratio. Hager discusses how gender analysis has helped researchers better recognize that the small and large fossils from the same era can represent either female and male members of one highly sexually dimorphic species, or individuals belonging to two different species, one robust and the other small.

Louise Fortmann, Heidi Ballard, and Louise Sperling's work on the environmental sciences again underlines the point that gender analysis is not something carried out in isolation but combines with and strengthens other methodologies. Their emphasis on "participatory research methods" is broader than, but consistent with, feminism. As they show, broadening notions of what counts as "science" often brings to light women's contributions and, more importantly, leads to reconceptualizing the environmental sciences. Fortmann, Ballard, and Sperling's several examples come from the realms of farming and forestry. First-world research on agrarian production systems proceeded for decades on the assumption that men were farmers and foresters while women were housewives. Women in various parts of the world, however, often do most of the subsistence farming and forestry and consequently possess specialized knowledge of plants and seeds. Broadening participation in research—that is, incorporating the knowledge of less-educated but skilled planters, harvesters, and seed selectors—can improve crop yields, better preserve biodiversity, and allow for sustainable harvesting. As Fortmann, Ballard, and Sperling argue, recognizing women's contributions has, in some instances, led to methodological innovation in management practices and policies in the environmental sciences.

In her chapter on geographic information systems (GIS) Mei-Po Kwan takes a slightly different approach, emphasizing how GIS, which has traditionally been seen as encompassing purely technical methods for managing and mapping geographic data, can serve as a tool for enhancing our understanding of women's lives. Kwan offers three highly interesting examples. Of particular note are the ways in which GIS has been deployed to understand gendered use of space. Employing GIS to map the daily paths of African American women in sample households in Portland, Oregon, Kwan is able to quantify how their lives are restricted spatially, not simply economically and socially. Understanding this dimension of urban design can assist governments in planning more equitable cities.

Taking women into account can also improve engineering designs. Several years ago, historian Rachel Weber explored how airplane cockpits had to be redesigned when women were admitted into the United States Air Force in the 1990s. As is often the case, changes made with women in mind improved the situation for men. The new cockpits not only accommodated the sitting height of the average woman but also of shorter men—who had previously also been excluded from careers as pilots (Weber 1997). In this volume, Tatiana Temm describes how an all-women design team at Volvo Car Corporation created a concept car designed especially for women. She emphasizes, however, that many of the innovations—greater visibility for shorter people, extra ease in opening doors, and the like—although designed for women, also improve the driving experience for men.

While researchers have produced a rich literature on a host of topics ranging from women in science to gender bias in scientific knowledge and the like, Charis Thompson argues in her chapter that policy in this area is often theoretically and empirically "anemic." She finds that researchers in the field of gender policy treat almost exclusively the (under)representation of women and minorities in science, often leaving aside more complex issues. Her contribution here on stem cell research begins to unravel some of the tangle in thinking about women, eggs, and embryos. The time has come, she notes, to begin in earnest the historical and contemporary study of the politics of gender and science, and to develop a clearer understanding of the different consequences that different approaches to stem cell research hold for women of different races and classes.

Moving Forward

It is abundantly clear that sexual divisions in physical and intellectual labor do structure institutions, knowledge, and everyday objects in our society. But it is also clear that gender analysis has not yielded results uniformly across the various fields of science and engineering. While examples of how gender has brought new insights abound in biomedicine, the life sciences, archaeology, primatology, and elsewhere, similar examples are not available for physics, chemistry, or electrical engineering, for example. Meg Urry argues in her chapter that photons have no gender, that gender bias, and hence the possibility for gender innovations, does not exist in physics—that is to say, in the knowledge created by physicists. It is true that the physical sciences have by and large resisted gender analysis (although, as Urry emphasizes, the culture of physics is highly gendered). There are several possible reasons why this is so. First, we observe that in disciplines such as biomedicine and biology that enjoy a good number of women practitioners, more progress has been made in knowledge issues. But which came first—the openness of the discipline to new intellectual insights or the greater numbers of women in those disciplines—is a topic open for research. One thing that is true is that the number of people trained in both physics (or chemistry) and gender studies is extremely small and something that should be remedied. Second, the lack of interest in gender analysis in the physical sciences may also be due to the fact that objects and processes of the physical sciences are less obviously gendered, if at all. That no gender dimensions exist in physics or chemistry, however, is currently a well-formulated hypothesis. We need to run the research.

Once we have made some headway developing gender analysis useful to the natural sciences, how do we mainstream this type of analysis in the day-to-day work of science and engineering? There are two next steps. First, we need to train students—undergraduate and graduate—along with faculty in how to integrate gender analysis into their research. While most people agree that students require advanced training in molecular biology or particle physics in order to excel in those fields, many believe that they can just "pick up" an understanding of gender along the way. Understanding gender, however, requires research, development, and training, as in any other field of intellectual endeavor. The NIH programs I described earlier work, for example, because a solid body of gender research on medical issues was available from a number of leading institutions across the United States.

Second, this is where policy kicks in. One of the goals of this volume is to move the NSF toward requiring that federally funded science integrate gender analysis into research design, where appropriate. The NSF is lagging behind other federal and international agencies in this regard. At the NIH, as noted above, the Office of Research on Women's Health requires proper consideration of sexual differences in medical research. At the European Commission also, the Directorate General for Research requires that project design address "systematically whether, and in what sense, sex and gender are relevant in the objectives and methodology of projects" (European Commission 2006; removing this requirement has been discussed. While using gender analysis in research is retained in the 7th Programme, compliance is not enforced; http://ec.europa.eu/research/science-society/index .cfm?fuseaction=public .topic&id=142 retrieved August 20, 2007). Moreover, a number of European countries, such as Sweden, have made increasing the number of women along with integrating gender analysis into research design part of their national science policy. Even where this is the case, however, more training in how to incorporate gender analysis into science and engineering research is needed. On a recent visit to Sweden I heard that although this is national policy, few researchers know what exactly to do.

Let me conclude by suggesting that much work remains to be done. One of the many tasks at hand is to continue to collect empirical examples of how gender analysis has enhanced theory or practice in specific subfields of science and engineering (see also Schiebinger 1999 and 2003). We also need to continue to develop frameworks of gender analysis that address these issues for sciences, such as physics and chemistry, where gender appears not to play as large a role in knowledge.

Let me emphasize again that this work is crucial to our efforts to recruit and retain women—we will not solve that problem until we solve the knowledge problem. It is intriguing that sciences, such as biomedicine, primatology, archaeology, and biology, where gender analysis has flourished, have relatively high numbers of women. In these fields and in many fields in the humanities, employing gender analysis has added spark and creativity by asking new questions and opening new areas to research. Can we afford to ignore such opportunities?