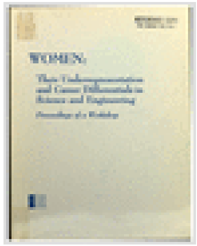

Women: Their Underrepresentation and Career Differentials in Science and Engineering : Proceedings of a Conference (1987)

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WOMEN:

Their Underrepresentation and Career Differentials in Science and Engineering

Proceedings of a Workshop

Office of Scientific and Engineering Personnel
National Research Council

Linda S. Dix
Editor

National Academy Press
Washington, D.C. 1987

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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ACKNOWLEDGMENTS

This proceedings volume is the result of the joint interest of the National Science Foundation (NSF) and the National Research Council's Office of Scientific and Engineering Personnel (OSEP) in the nation's human resources.* Each has had a strong, longstanding commitment to understand populations that are underrepresented in the scientific and engineering work forces. For women this underrepresentation has been extensively documented in the congressionally mandated biennial NSF reports, Women and Minorities in Science and Engineering. The reasons for this underrepresentation are less well-understood. Why are girls less apt to participate in advanced math and science courses in secondary schools? Why do fewer women than men pursue undergraduate degrees (and, subsequently, graduate coursework) in science and engineering? and What factors might influence these decisions by females to forego careers in scientific disciplines?

We are greatly indebted to the authors whose commissioned papers attempted to answer these questions--Susan F. Chipman, Lilli S. Hornig, Jane Butler Kahle, William K. LeBold, J. Scott Long, Marsha Lakes Matyas, and Harriet Zuckerman--and to M. Elizabeth Tidball, who chaired the workshop and offered helpful advice from the project's inception. Their contributions constitute the substantive heart of this project.

We are also grateful to many other individuals who contributed to this project. Michael Crowley, director of NSF's Scientific and Technical Personnel Characteristics Studies Group, was the guiding force behind the convening of the Workshop on the Underrepresentation and Career Differentials of Women in Science and Engineering, held on October 9, 1986. Gwendolyn L. Lewis, formerly OSEP's data services officer, compiled information from numerous sources in order to structure the workshop's agenda and to ensure that scholars with the appropriate backgrounds and expertise would be involved in this exploratory workshop. Linda S. Dix, OSEP's administrative officer, shepherded this proceedings volume through the production process. Nancy Conlon, senior science resources analyst in NSF's Scientific and Technical Per-

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*Throughout this proceedings volume, the views expressed by the authors and other participants are those of individuals and are not to be attributed either to the National Research Council or to the National Science Foundation.

sonnel Characteristics Studies Group, worked closely with OSEP staff as the project developed. The technical support of Yupin Bae, research assistant, and secretarial support of Joan M. Grady, Agnes Israelsen, and Catherine D. Jackson are also most appreciated.

ALAN FECHTER
Executive Director

CONTENTS

INTRODUCTION

Women and members of minority groups, markedly underrepresented in science and engineering in this country, are an increasingly important source of talent for maintaining world leadership in these areas. Recent reports documenting this underrepresentation, prepared by NSF for the U.S. Congress, have been limited to statistical descriptions of the differences in participation rates. OSEP agreed to sponsor this workshop to explore what is known about the causes of the observed underrepresentation and differential participation of women at all educational levels and about the patterns and causes of their differential career development relative to men.*

Four commissioned papers covered critical parts of the educational pipeline--precollege, undergraduate, and graduate education--as well as postgraduation careers, and two researchers served as critical discussants of them. As noted in the papers,** many factors influence the underrepresentation of girls and women in science and engineering. In general, the authors found that many students, teachers, parents, and researchers imagine that the fields of science, engineering, and mathematics are masculine and that differences in scientific ability amy be attributable to gender differences. Specific findings include:

- College-bound women lack adequate preparation in mathematics and physical science to pursue quantitatively-oriented science programs in college and, hence, quantitatively-oriented careers.
- Many colleges base admission on one's preparation in mathematics and physical science and on Scholastic Aptitude Test scores, reducing the pool of women eligible for admission to institutions and to programs that focus on engineering and science.
- Less financial aid is available for women students in science and engineering than for the male counterparts.

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*OSEP and its predecessor, the Commission on Human Resources, sponsored the Committee on the Education and Employment of Women in Science and Engineering (CEEWISE) from 1973 until 1982. That committee's work contributed significantly to the understanding of career differentials discussed in this report.

**Throughout this proceedings volume, the views expressed by the authors and other participants are those of individuals and are not to be attributed either to the National Research Council or to the National Science Foundation.

- Women enrolled in both undergraduate and graduate science courses show diminished self-confidence.
- Employers, whether in industry or academia, do not accommodate women scientists and engineers who choose to put their careers on hold briefly while giving birth and raising children.

The authors cited a number of societal, institutional, disciplinary, and individual efforts that could contribute to the more equitable treatment of girls and women in science and engineering:

- Concentrated attempts to improve the achievement in science and mathematics of students--particularly, girls and members of ethnic minority groups--beginning at the elementary school level. This might be accomplished by a combination of inservice training of teachers, the use of curricular materials that provide a more balanced presentation of male and female scientists, the development of strategies for educating parents about the opportunities available to both boys and girls, and the availability of role models who might serve as mentors.
- Comprehensive institutional programs that include the following elements: recruitment, retention, employment, and evaluation.
- Participation by industry, professional societies, and the government in activities involving women in engineering. Such participation would include funding (1) to evaluate successful programs as well as to implement them more widely and (2) to influence women's participation in science programs at all levels.

Besides research findings, participants were asked to specify important areas for future study based on an evolving understanding of these issues. The following unanswered questions should be studied:

- What determines one's early development of interest patterns and self-perceptions about ability in science and mathematics?
- What characterizes successful precollege intervention programs and successful programs designed to encourage greater admission and retention of women in college engineering courses?
- How can change be effected in society's attitude toward women's roles in the work force and the subsequent change of women's attitudes about and awareness of science and engineering as career fields open to them?
- What are the structural barriers to women's pursuit of graduate education in mathematics, the sciences, and engineering?
- How different are the career aspirations of women and men scientists and engineers? What is the relationship between career aspirations and career attainment?

The workshop provided an opportunity to review the issues in depth. It is hoped that this volume will clarify them and help to shape intervention strategies to increase women's participation and status in these important fields.

Linda Dix

OVERVIEW OF PRESENTATIONS

The workshop papers focus on precollege, undergraduate, and graduate education and on career development. Each examines levels of women's participation and deals broadly with questions of ability, performance, and environment. In dealing with these questions, the authors discuss the adequacy of the research base in identifying the factors associated with less participation and differential achievement.

The Kahle/Matyas paper describes institutional and non-institutional environments at the precollege level that discourage female participation in science and engineering through male stereotypes and role models and through teacher, counselor, and parental expectations of greater achievement for males. Differences in parental expectations and the stereotyping of scientists as male are established by the time children enter kindergarten. Once in the school system, girls are confronted with an educational system that favors male learning styles (competitive) over female learning styles (cooperative), teachers who interact more with male students than with female students, and the use of sex-biased texts. Research indicates that girls lose confidence in their mathematical abilities in the first years of schooling, relative to boys of equivalent ability, and that this pattern persists. Lack of confidence influences the selection of advanced courses in mathematics and science, participation in extracurricular science activities, and achievement test scores.

The LeBold paper finds that despite the enormous advances made by women in undergraduate science and engineering enrollments and degree attainment, women remain underrepresented in many fields--especially in the physical sciences and engineering. The paper examines possible causal factors. One is the number and proportion of women with the necessary quantitative and computer backgrounds to enter these fields. While the gender gap in this area may be narrowing, the LeBold paper indicates a growing disadvantage for women with regard to their computer backgrounds. Another causal factor is that career opportunities in business and the professions are attracting women who might otherwise pursue science and engineering careers. Possible factors include the discontinuation of industrial, federal, and foundation programs to attract underrepresented groups to science and engineering and the absence of a critical mass of peers at some institutions in selected physical science and and engineering fields.

Field differences are also an important factor in patterns of student support at the graduate level. In her paper, Lilli Hornig analyzes what is known about patterns of student financial support, how those patterns affect female and male graduate students differentially, and the large and critical data gaps that exist. Under the headings "ability," "access," and "motivation," Dr. Hornig reviews the factors affecting persistence of male and female graduate students in science and engineering. She notes that while some documented ability differences favor women and some favor men, the apparent financial disadvantage in graduate support for women and the lack of equal incentive in the opportunity structure of science and engineering careers may be explanations for their continued underrep- resentation in these fields.

Data on differential career achievements in science and engineering, presented by Harriet Zuckerman, show that women lag relative to men in promotions, salaries, research performance, and receipt of awards and that women are more frequently under- or unemployed. In industry but not in academia, where men and women doctorates .are equally apt to become assistant professors, differences in career development begin with disparities in first jobs between males and females of equal educational backgrounds and abilities. Later, differences widen, always favoring males, as the careers of the men and women in any age group progress. There has, however, been some narrowing of the overall gap between men's and women's careers over the past several decades. Zuckerman describes four classes of possible reasons for the observed disparities: (1) differences in measured ability; (2) differences arising from social selection based on gender discrimination and role performance; (3) differences arising from self-selection based on family roles and extent of career commitment; and (4) differences that are the result of accumulation of advantage and disadvantage. She finds that the evidence documenting the validity of each of these classes of reasons is ambiguous--largely because of the complexity, incoherence, and partial nature of the available data--but favors the explanation emphasizing accumulation of advantage.

EQUITABLE SCIENCE AND MATHEMATICS EDUCATION: A DISCREPANCY MODEL

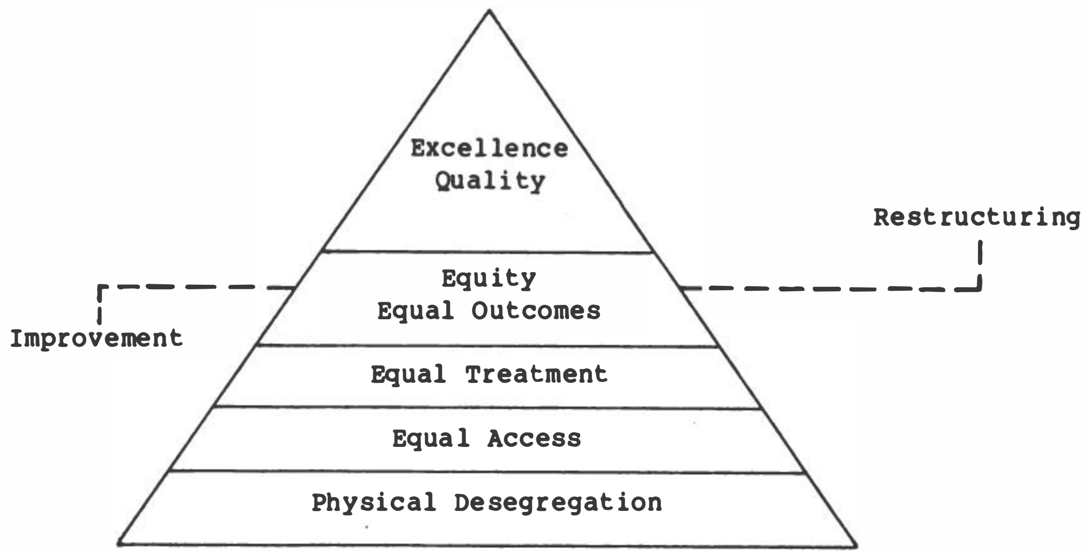
Jane Butler Kahle and Marsha Lakes Matyas

Introduction

A 15-year-old girl in rural America once said, "There are some women scientists; but men have been in it longer. Women can do the same job as men. They may have a different way of thinking and might improve science" (Kahle, 1985:68). Her words were fortuitous because they were spoken a few days before Barbara McClintock won the Nobel prize for looking at maize in a different way and for thinking about genetics in a different manner. McClintock's work, unrecognized and even scorned for decades, epitomizes the concern that not only individual women but also the scientific community and society as a whole suffer because of a lack of equity in science and mathematics education. Perhaps Maria Mitchell, one of the first women to be recognized as a scientist, said it best:

> In my younger days, when I was pained by the half-educated, loose, and inaccurate ways which we (women) all had, I used to say, "How much women need exact science," but since I have known some workers in science who were not always true to the teachings of nature, who have loved self more than science, I have now said, "How much science needs women." (Maria Mitchell's presidential address to the Third Congress of Women in 1875; quoted in Rossiter, 1982:15)

Over a century later, as the McClintock story dramatized, science and engineering still need women. Study after study in the developed Western world suggests that girls and women receive very different educations in mathematics and science than boys and men do. Some of the differences are subtle; others are overt. This paper examines both types from preschool to college, focusing on differences in educational settings while acknowledging the impact of cultural, sociological, and environmental factors upon educational institutions. Using McCune's (1986) model of desegregation (Figure 1), it proposes that today (1) equal access is accepted and (2) once a student is enrolled, equal treatment is assumed. However, equal outcomes have not been achieved in science and mathematics education.



SOURCE: S. McCune, Bridging the Gap Through Responding and Restructuring, paper presented at the Bridging the Gap Seminar, McRel Sex Equity Center, Kansas City, February 1986.

Figure 1 Levels of desegregation.

The Discrepancy Model

That proposition will be developed by employing a discrepancy model that first examines the ideal state (in this case, what constitutes equitable science education). The ideal state is constructed from objective evidence prior to the description of the actual state, today's science and mathematics education. And, last, the pathway from the actual to the ideal is delineated. In developing the model, a search of the work of experts from a variety of fields--for example, mathematics, science, education, sociology, and psychology--is a prerequisite, for the ideal state must not be based on opinion. Rather, it should be developed from the vast array of research and writings available. The actual state, too, is built from the writings of a variety of experts, including classroom teachers, science and engineering professors and educational researchers, education researchers, industrial managers, and professional colleagues. Brick by brick the actual state is constructed. Then, the two states are compared. Eventually, the goal is an evolution from the actual to the ideal state or from inequitable to equitable education in science and mathematics.

The Ideal State of Science and Mathematics Education

Researchers who have sought to identify factors leading to excellent and equitable science and mathematics education and who have analyzed curricula, teacher behaviors, and classroom climates concur that an ideal science or mathematics classroom or curriculum equally benefits all students. After conducting a 6-month case study of a Colorado science teacher noted for her success in motivating girls to continue to study science, a researcher summarized that premise:

> I think that rather than identifying a teacher who consciously encourages females in science, we have simply identified a very good teacher, whose talent, commitment, and rapport with her students combine to make the study of science an interesting and enjoyable endeavor. (Kahle, 1983a:26)

In science, particularly, reaching the ideal state is hampered by the prevalent, and perhaps irrelevant, popular image of science, which will be described in the actual state. For now, let us agree that in the ideal state science as well as mathematics will have factual rather than romanticized images. Both, in the ideal state, will be characterized not as the objective discovery of truth but rather as very human and humane endeavors. One result of a more accurate characterization of science will be a change in science's image:

> [The] view of scientific activity, in which a range of interpretations is seen as central, not as abnormal, and in which people are allowed to express and justify different points of view, [will] be much less sexist than the existing stereotype. (Harlen, 1985:545)

In both disciplines, understanding, rather than absolutes, will be emphasized. Creativity and social discourse will become an integral part of school science and mathematics as they are in actual science and engineering.

Elementary School

> The opportunity for children to experience science activities exists at the elementary school level perhaps more readily than at later stages of education. If we wish to increase girls' access to science, therefore, science at this early level has a vital part to play. (Harlen, 1985:545)

Many have argued that the elementary school is the critical place for change: change in formal and informal science and mathematics curricula, change in classroom instruction and interactions, and change in school structure and socialization. Although, compared with secondary schools, fewer studies or intervention projects have been conducted at the elementary level, a pattern for change is beginning to develop, one which indicates the ideal situation of tomorrow.

<u>The Curriculum.</u> The anomoly exists that one ideal type of curriculum for elementary school science has existed for several decades, yet it is little used, and if implemented, it is frequently misused. That is

the student-centered, activity-based curricula of the 1960s and 1970s: SCIS, Science Curriculum Improvement Study, and SAPA, Science, A Process Approach. They have faded from classrooms for three primary reasons: teachers have not understood the scientific principles that the materials promulgated, classrooms have not been organized for small group interactions in science, and schools have not provided the equipment or the scheduling required. However, recent analyses make a strong case for their redemption in the ideal state. For example, a review of 34 evaluative studies indicates that children using the "hands-on" curriculum achieved better on every measure of achievement than did those children studying "textbook" science.

In fact, one analysis of 13,000 children in 1,000 U.S. classrooms has demonstrated that children who have experienced the innovative materials surpass those who have received traditional instruction. They achieve higher on measures of science processes, creativity, perception, logic, development, science content, and mathematics. In addition, the opportunities provided by the "hands-on" materials for experimentation--as well as for handling instruments, for making measurements, for observing natural phenomena, for collecting data, and for making interpretations--have the potential of producing equal outcomes.

Study after study documents that girls and boys enter elementary school with equal interest in science but with unequal experiences in science (Iliams, 1985; Kahle and Lakes, 1983; Kelly, 1985). The "hands-on" curricula not only provide opportunities for the experiential background needed by all students for secondary and tertiary science courses, they also provide girls with experiences not readily accessible to them otherwise. As Iliams has stated, "Girls are less likely than boys to make up the education deficiency in out-of-school experiences" (1985:79).

A group of science and mathematics teachers in independent schools has suggested aspects of the ideal mathematics curriculum. For example, problems will be related to everyday financial decisions; parents will be encouraged to involve girls in family decisions; and practice with decoding "word problems" will be integrated into the reading curricula.

In addition to an activity/process/child orientation, elementary science and mathematics curricula in the ideal state will have the following characteristics, according to Whyte (1984):

- Activities that begin with everyday phenomena as starting points;
- Activities that foster cooperative, rather than competitive, investigations;
- Texts and other materials that show some girls and women in active roles and some boys and men in nurturing roles;
- Activities that encourage all children to be involved in risk-taking situations;
- Content that is success, not failure, oriented;
- Content that is based on values related to interaction and equilibrium, rather than on values related to control and dominance; and

- Texts, materials, and examples that use both male and female prototypes.

In addition to substantive curricular changes, elementary science as well as mathematics in the ideal state will be taught in "prime time"--that is, in the morning, which has traditionally been reserved for "important subjects" such as reading, spelling, and arithmetic.

The Classroom. Partly as a result of the process curricula and partly because of changes in the education of elementary teachers, instructional interactions and teacher behaviors will be different also. Some of the suggested changes are firmly grounded in recent research. For example, an analysis of "desired" versus "actual" activities in science reveals that elementary-age girls wish to do many more things than they have actually done (Kahle and Lakes, 1983). Teachers, cognizant of such studies, will provide opportunities for girls to use scales, magnifying glasses, balances, telescopes, and microscopes.

A classic experiment--conducted by Rennie, Parker, and Hutchinson (1985) in western Australia--demonstrates the effectiveness of innovative in-service training upon student outcomes. Briefly, they provided matched pairs of elementary teachers, both male and female, with intensive training in the skills of teaching electricity as well as with information about nonsexist teaching. A comparable group received only the skills training. Their results indicate the efficacy of changing teaching behaviors to effect changes in student attitudes. They found "a slight but consistent tendency for students in the Experimental Group classes to perceive girls as more competent with electricity than did students in Control Group classes" (Parker, 1985:12). When they asked the Year 5 children if they could become electricians, 90 percent of the boys in both the experimental and control classes responded positively, while 85 percent of the girls in the Experimental Group said "yes" compared to only 70 percent of the girls in the Control Group (Parker, 1985).

Their study illustrates the effect of experience on both attitudes and self-confidence. In three different countries, definitive studies have shown that experience makes the difference; that is, boys and girls express similar interest in topics with which they have had experience (Kahle, 1985; Parker, 1985; Smail, 1985). Therefore, instructional interactions in the ideal state must provide experiences with the equipment and instruments of science and with the models and theories of mathematics rather than with their facts. One practical change is that in the ideal classroom, boys and girls will have equal access to the equipment and resources for science and to the models and resources for mathematics. Harlen (1985) noted other instructional interactions that the ideal classroom would include:

- Assigning boys and girls equally to tasks that involve lifting, carrying, tidying, and cleaning up;
- Promoting cooperative, not competitive, grouping of students for science and mathematics;
- Prohibiting the practice of "calling out" answers to teachers' questions;

- Initiating more wait-time for girls' responses;
- Monitoring nonverbal behaviors, such as loss of eye contact or rapid nodding, which encourage girls to cut short their responses; and
- Engaging girls as often as boys with both positive and negative feedback concerning their intellectual performances.

Elementary teachers do not consciously promulgate sexism in their classrooms; rather, their unplanned teaching acts may lead to such behaviors and practices. In the ideal state, teachers will be cognizant of the effects of such unplanned teaching acts and, therefore, be able to monitor them. Teachers not only verbally communicate their expectancies by more frequently calling and/or praising students for whom they hold high expectations, they also communicate them, perhaps more powerfully, in nonverbal ways. In the ideal state, teachers will expect comparable work and behavior from both boys and girls and will reward both in similar ways.

The School. Changes are needed in the elementary school as an institution in the ideal state. Basically, convenient management techniques that consistently separate children on the basis of sex will be avoided. For example, students may be lined up according to the alphabet rather than by gender. Or they may be separated by hair or eye color, by handedness, by reading group. On both the playground and in the classrooms, areas should be specified for quiet and adventurous activities, and both boys and girls should be encouraged to participate in both types. Older boys as well as girls should be assigned to assist with younger children. The school in the ideal state will provide an optimal setting for science and mathematics instruction because there will be equity in the corridors as well as in the classrooms.

Secondary School

> Of all the stages of life, adolescence is the most volatile --full of promise, energy, and, because of newly achieved freedom and potency, substantial peril. In its freshness, adolescence is attractive. In its enthusiasms, it can be, to older folk at least, exhausting. For most people, it is pivotal: it is the time of life when we find out who we are becoming, what we are good at, what and who we like. What happens in these years profoundly affects what follows. (Sizer, 1984:1)

In the ideal state as well as in the real one described above by Sizer, secondary schools and their classrooms of mathematics, biology, chemistry, and physics are pivotal in terms of retaining students in science and engineering; for one's failure to enroll in either science or math firmly, if not permanently, closes future laboratory doors. First, the description of ideal secondary science curricula, classes, and schools is derived from the findings of three recent major studies, one in the United States and two in the United Kingdom. Next, a comparable description will describe the ideal state of mathematics in secondary schools.

In science, a national study under the auspices of the National Association of Biology Teachers (NABT) identified and observed biology teachers who were successful in motivating tenth-grade girls to elect optional physics and chemistry courses (Kahle, 1983a, b). Selected teachers from Maine to California were observed, parents and principals were interviewed, and past and present students were surveyed. Approximately 395 children of all races and from varied backgrounds participated in the study, conducted in diverse communities across America. It provided a composite picture as well as a collective pool of data from which commonalities were identified and generalizations were made. Indeed, the study described facets of the ideal curriculum, teacher, classroom, and school.

One of the projects in the United Kingdom, Girls in Science and Technology (GIST), was action-based research--that is, its teacher participants were actively involved in the intervention program (Kelly, et al., 1984). GIST involved 10 comprehensive schools in the large manufacturing environs of Manchester and studied more than 2,000 children from the time they entered lower school (age 11) until they made their subject choices at age 14. Although its findings portrayed the actual classroom and school, the research team developed some ideal curricula and hypothesized about ideal situations.

The last study, also from the United Kingdom, differed from the first two in that it dealt with interpretation rather than actual intervention. Two researchers, Johnson and Murphy (1986), interpreted the results of the national APU survey in order to suggest ways to improve science education for girls. Their suggestions, too, portend the ideal state.

The Curriculum. Although the ideal curriculum will be derived from all three studies, it will be filtered through three factors shown to influence subject choice: interest (significantly more important for girls than for boys), previous performance, and career value.

The GIST project developed and tested new curricula as part of its 4-year study; that is, when the teacher-participants requested new or different materials, they were developed. Curricular materials were designed to be what Jan Harding (1985) has called "girl-friendly science." That is, they had the following characteristics:

- Focused on relationships as well as rules,
- Focused on people as well as machines,
- Developed a pragmatic rather than a dogmatic approach,
- Viewed the world as a network rather than a hierarchy of relationships,
- Emphasized the aesthetic as well as the analytical aspects of science, and
- Focused on nurturing living beings as well as on controlling inanimate things. (Smail, 1984:27)

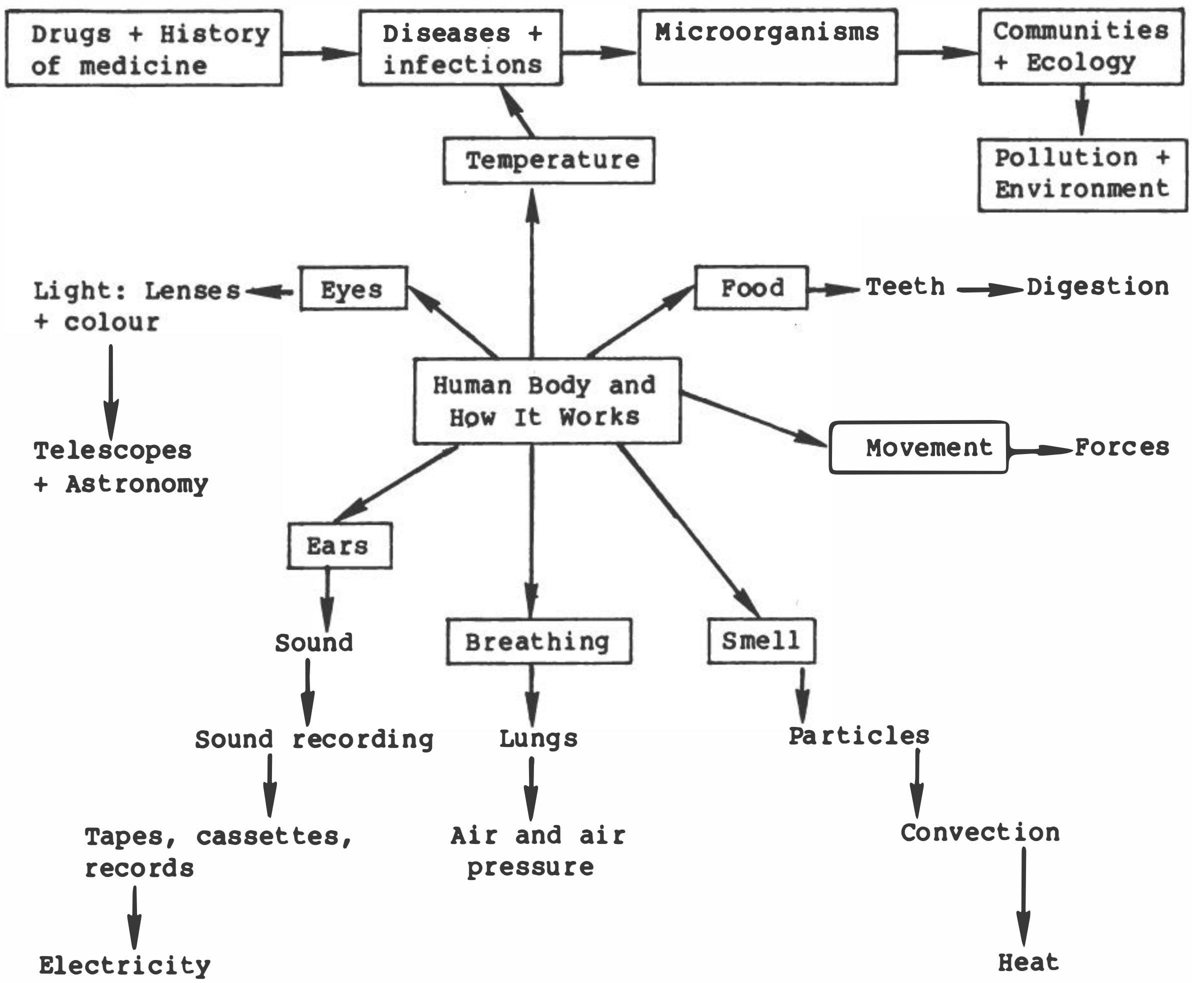


Figure 2 Concept map of a lower-school science curriculum based on the human body.

The proposed curriculum would cover three years of general science from about ages 11 to 14. Topics in physics, chemistry, and astronomy as well as basic biology would be included under the rubric of human biology (as shown in Figure 2). The GIST researchers and teachers used the human body as the integrating topic because an initial survey demonstrated that it was the only science topic among eight choices in which 11-year-old boys and girls both showed a high interest, as shown in Table 1.

The GIST project, as well as the other two, also proposed the integration of the actual contributions of women scientists into the curriculum. In addition, both British projects stress the inclusion of "tinkering" activities in order to overcome the lack of such experiences by girls. The results of both the GIST and the NABT projects

TABLE 1: Expressed Interest in Science Topics by 11-Year-Old Students in the GIST Project (in percent)

Girls		Boys	
Human body	25.7	Rockets and space travel	19.9
Birds	21.8	How cars work	18.1
Seeds	21.2	Human body	15.2
Pond life	14.0	Birds	11.7
Rocks/fossils	10.3	Pond life	11.2
How cars work	3.5	Seeds	10.3
Chemistry set	1.9	Rocks/fossils	9.1
Rockets and space travel	0.6	Chemistry set	4.5

SOURCE: B. Smail, Girl-Friendly Science: Avoiding Sex Bias in the Curriculum, London: Longman, 1984, p. 13.

demonstrate that the ideal secondary science curriculum must provide experiences with rotating three-dimensional figures in space, with drawing and conceptualizing three-dimensional forms, and with projecting curvilinear distances and outcomes. Such experiences increase a child's visual-spatial ability. Since girls usually have less experience with the toys, games, and activities that enhance spatial ability, opportunities must be constructed in the curriculum. The GIST project has revealed that although boys initally score better on spatial ability tests, the enrollment of girls in one technical craft course eradicates the gender difference (Kelly, *et al.*, 1984).

All three projects concur that extensive laboratory work is needed in the ideal curriculum. The laboratory builds upon two facets: (1) interest and (2) experience. Perhaps a 15-year-old girl in Louisiana described the interest aspect best when she said,

> I enjoy working with microscopes. We had a cow heart and we opened it up. [We] looked in the microscope at the different parts of the inside of the heart and I enjoyed that. (Kahle, 1985:54)

The need for experience with the actual tools and techniques of science is supported by the findings of all three major studies. Boys as well as girls express anxiety if they do not have sufficient past performance against which to gauge future success. For example, the NABT study found that girls express little anxiety about focusing a microscope with which they have had experience but great anxiety about wiring an electric circuit for which they have had none. Boys, on the other hand, express concern about taking the temperature of a living organism, a technique with which they have had less previous experience. In addition, the GIST project suggests that the image of science as dangerous inhibits girls in partaking equally in some science experiences. Safety precautions in the ideal curricula, therefore, will be expressed in a routine, nonalarming way.

The NABT study suggests that the ideal science curriculum will also feature alternative and supplementary materials, teacher-developed materials that include examples and exemplars drawn from the common experiences of girls (sewing machines and volleyball) as well as those of boys (cars and football). In addition, the NABT study indicates the value of career information in ideal curricular materials. For example, over two-thirds of the children in the NABT study noted that career information was important. All of the studies recommend two basic changes in science curricula. First,the lack of sexism in published texts and in teacher-prepared materials as well as in teacher examples, language, and humor will be important. And, second, an infusion of informal counselling activities that provide both science and technological career information will be a prerequisite.

Participation in science hobbies and science-related extracurricular activities is an excellent predictor of high school science interest (Hasan, 1975; Wright and Hounshell, 1981) and of later undergraduate and graduate work in science (Neujahr and Hansen, 1970). In the ideal state, male and female students will participate equally in science and mathematics extracurricular activities and will have opportunities to encounter science and engineering role models of both sexes.

The Classroom. The NABT study focused primarily on teaching behaviors and instructional strategies that encourage girls as well as boys to continue to study science and mathematics. A subsequent study analyzed the practicality of extending its findings to the practices of other teachers. Combined, the two projects provide a perspective on both what is preferable and what is practical in the ideal secondary science classroom. Specific instructional strategies, applicable in the ideal state, include a focus on classroom discussion as well as individual and laboratory work. In addition, diverse media as well as field experiences will be used, and independent projects and library research will be integrated into the instruction. Furthermore, three unique findings portend changes in instructional patterns: (1) teachers who are successful in encouraging students to continue in science and mathematics quiz or test their students once a week; (2) they encourage creativity, noted by 58 percent of boys and 67 percent of girls; and (3) they foster basic skill development, according to over 70 percent of both boys and girls surveyed. The implementation of science and mathematics activities that develop creativity and originality while teaching basic skills will be an important change in the ideal science classroom. The infusion of creativity will add a new dimension to the image of classroom mathematics and science, while competency in basic skills such as measuring, graphing, and titrating will increase interest as well as the probability of success in science and engineering for all students. Since ethnographic studies indicate that girls are more interactive during individualized and some small-group activities, science teaching will favor that style of instruction rather than the whole-class mode (Tobin and Garnett, 1986).

All three projects, as well as innumerable other studies, have analyzed teacher behaviors; their findings allow us to describe teacher behavior in the ideal state. The ideal science teachers, both men and women, will practice what Shirley Malcom (1983b) calls "directed intervention"--that is, all students will be actively and positively encouraged to participate, to respond, and to question. Since Kelly (1985) suggests that maintaining gender differentiation is not primarily due to teacher interactions but rather is due to the behavior of the children themselves, directed intervention may be one of the best ways to encourage girls.

In 1981, Galton identified three teaching styles in science: **problem solvers**, involving a high frequency of teacher questions and a low frequency of pupil-initiated or -maintained activities; **informers**, using teacher delivery of facts and an infrequent use of questions except to recall facts; and **inquirers**, using pupil-initiated and -maintained experiments as well as inferring, formulating, and testing hypotheses. The three major studies support Galton's conclusion that girls prefer the latter style of teaching--that is, the inquirers. Interestingly, it is the style most often used in biology classes, often selected by girls, while the problem-solver strategy is more frequently used in physics, which few girls elect to study. An adaptation of the inquiring style into all science and mathematics classrooms will benefit both boys and girls, for science is a cooperative, social activity that evolves due to a cycle of hypothesis testing, and mathematics relies on social discourse as theories are tried and tested.

The NABT study suggests another aspect of the ideal science classroom: all of the exemplary classrooms--whether in a wealthy suburban area or in an urban ghetto--provided pleasant, attractive, and stimulating environments for learning science. Future classrooms will be filled with posters, aquaria, terraria, plants, animals, models, scales, levers, computers, and other devices that will motivate girls as well as boys to study science and mathematics.

The School. All of the teachers in the NABT study indicated that their support and encouragement came from students' parents and their communities rather than from their peers and superiors. They, at least, experienced benign neglect and were able to use innovative materials and techniques without bureaucratic interference. The ideal school, however, will identify and encourage creative science and mathematics teachers. In addition, it will provide both a setting and administrative services to foster learning free of sex-role stereotypes. Courses will be scheduled so that students may take as many science and mathematics options as they wish. In addition, traditionally female and male classes will not conflict so that girls, too, will enroll in courses such as electronics, calculus, drafting, metal-working, and physics. Furthermore, counselling or guidance offices within schools will provide non-traditional information rather than promulgate sex-stereotyped course and career selections. Changes within the counselling system will be among the most important ones in an ideal school. Informed choice will be the key for both boys and girls in the future, ideal school.

Transition. Sue Berryman (1983) discussed the pipeline that leads to science and engineering careers. She has found that women leave the pipeline near its end--i.e., at the doctoral level--while minorities exit from it between high school and college. The transition stage between high school and college, therefore, is critical, particularly for minority women. The ideal state, however, has excellent models for the retention of women in science and engineering courses. These models are primarily from the diverse "women in engineering programs" in the United States. Many of those programs have used undergraduate women in engineering to recruit and encourage high school girls; this practice will be a common one in the ideal state.

Gardner (1986) has applied the same technique with science majors and has found it successful. Likewise, many women and minority mathematics' programs at the University of California and Mills College have successfully used role models, slightly older than the target group of students, to recruit applicants to nontraditional courses. In addition, recent students have identified nonacademic factors that predict women's attrition from nontraditional courses (Gardner, 1986; Matyas, 1986). In the ideal state, prediction formulas will be used to assess the probability of competent women remaining in nontraditional majors and appropriate counselling will be used as needed.

The Actual State of Science and Mathematics Education

> Our children and our students are participants in a complex process that equips one sex with math, science, and technical skills indispensable to functioning in the adult world, while it fails to encourage the same development in the other sex. Although the lives of individual women are the most negatively and directly affected, the loss to both sexes is immense. (Skolnick, et al., 1982:2)

In the fall of 1985, the Office of Opportunities of the American Association for the Advancement of Science convened researchers to discuss the current status of research concerning precollege and minority students in science and mathematics. The following five points arose during the discussion:

(1) More research had been done on females than on minorities;
(2) More research had been done at the senior high school level than at the junior high and elementary levels;
(3) Almost no data had been collected, analyzed, and reported by sex and race simultaneously, resulting in little information about minority females;

(4) Most of the research had been correlational with only a few studies employing theoretical models, causal analysis, experimental techniques, or longitudinal designs; and
(5) Research had focused primarily on finding differences between boys and girls, rather than on determining optimal learning situations.

Factors leading to the above state of knowledge as well as descriptors of the actual state of science and mathematics education will be discussed in this section. The focal point of the discussion will be the image of science, engineering, and mathematics in the minds of students, parents, and teachers.

Today, in the minds of students and in the perceptions of teachers, science and mathematics are masculine. Indeed, the scientist has replaced the cowboy in the adolescent's imagination as the hero, or anti-hero, who is fearless, strong, and lone. It is futile to argue that since that image may be largely derived from the media, television, movies, and advertisements, it cannot be changed. There is a wealth of evidence to support the contention that regardless of how, when, and where the masculine images of science and math evolved, schools and universitites, teachers and professors sustain it. In fact, gender is recontextualized within schools so that "the notion of appropriate behavior for each sex [is] converted into appropriate academic disciplines" [MacDonald (1980), in Kelly (1985)]. Once subjects have acquired a gender status, in this case, masculine, participation in it is seen to reinforce a boy's masculinity and to diminish a girl's femininity. The reverse is obviously true for feminine subjects such as French or typing.

Two types of studies have validated the masculine images of science and mathematics. In one type, students have been asked to rate school subjects on a number of dimensions, one of which is a masculine/feminine scale. The results indicate that woodworking and physics are seen as the most masculine subjects, followed by math and chemistry. While history and biology are rated as neutral subjects, English, French, typing and cooking are viewed as feminine ones (Weinreich-Haste, 1981). Although comparable studies have not been done in mathematics, another verification of science's image is found when children and teachers are asked to draw a scientist. Overwhelmingly, the drawings portray white, disheveled males (Chambers, 1983; Kahle, 1986b; Schibeci, 1986). What is the effect of this masculine image on students, teachers, curriculum, and courses? Alison Kelly maintains that "[T]he masculinity of science is often . . . the prime reason that girls tend to avoid the subject at school," and she suggests that "schools could play a transformative, rather than a reproductive, role in the formation of gender identities" (Kelly, 1985:133). There is every reason to believe that although the research summarized is from science, a comparable situation exists in mathematics.

According to Kelly (1985), there are at least four distinct senses in which science is masculine:

(1) In terms of numbers: that is, who studies science at school, who teaches precollege and college science, and who are recognized as scientists (e.g., National Academy, Nobel laureates, NSF fellowships and research grants).
(2) In terms of packaging: that is, the way science is presented, the curricula and instructional techniques, the applications and examples as well as the texts and other published materials.
(3) In terms of practice: that is, classroom behaviors and interactions such as teacher expectancies, sex role stereotyping, student-teacher interactions, and student-student interactions.
(4) In terms of biological differences: that is, genetic or hormonal factors.

Today, numbers, packaging, and practice all lead to a masculine image. In today's media and press, any differences found in the achievement levels or aptitudes of boys and girls in science and mathematics are often attributed to inherited abilities. Therefore, all four factors will be discussed and described in the actual state of science and mathematics education.

Numbers

The numbers of boys and girls who study science and mathematics and of men and women who practice science contribute to their masculine images. In one sense, the media's image of a white male scientist or mathematician accurately reflects the situation; there are more male scientists and mathematicians, and they have higher status.

In elementary education the real issue lies behind the overt numbers of students and in the covert ways in which boys and girls experience science and arithmetic. Research suggests that boys and girls bring different scientific and quantitative experiences to school and that in school they receive very different educations in science and mathematics. Specifically, from England (Smail, 1984), the U.S. (Kahle and Lakes, 1983), and Australia (Parker and Rennie, 1986), there is clear documentation that fewer girls than boys handle science equipment, perform science experiments, or participate in science-related activities. The differential backgrounds that boys and girls bring to elementary school are perpetuated by them.

In addition, international projects report that although boys and girls express interest in slightly different types of science, the overall levels of their interest are similar. Furthermore, for both boys and girls, interests are directly related to areas of daily experience--that is:

> Where the experience is one which is likely to be universal (e.g., earthworms, shadows, germs, water and weather), very little sex-differentiation of interest is shown. In other areas, such as wheels and motors and growing a vegetable or flower garden, where boys' and girls' out-of-school experi-

> ences are likely to be quite different, clear sex-stereotyping is revealed. (Parker and Rennie, 1986:177)

In mathematics there is clear documentation that boys, compared with girls, are expected by teachers to perform better, receive more teacher praise and criticism concerning mathematical performances, and excel in competitive games or chalkboard contests (Eccles, 1984; Wilkinson and Marrett, 1985). Clearly, the "numbers game" in elementary school is a subtle one. Equal numbers of girls and boys may sit through science and arithmetic lessons, but they participate in them in unequal ways.

The image of mathematics and science courses becomes more masculine in secondary school, where the numbers of boys taking science and mathematics as well as of men teaching science and mathematics increase. In the United States, only 24 percent of secondary school science teachers are women, and it may be safely said that most of them teach biology. Although virtually all high school students take biology (which functions as a required, introductory science course), only 30 percent of high school girls, compared to 39 percent of boys, take chemistry while physics, taken by 26 percent of all high school boys, is studied by only 14 percent of American girls. Overall, boys take one-fourth more year of high school mathematics and one-third more year of physical science than do girls, and the differences are found within each of the racial/ethnic groups (NSF, 1986).

In mathematics a similar situation is found. Although equal numbers of boys and girls study algebra and geometry, boys compared with girls are more likely to enroll in trigonometry (26 percent versus 20 percent) and calculus (8 percent versus 6 percent). Consistent sex differences in mathematics performance do not arise until students are in high school (Chipman and Thomas, 1985; Eccles, 1985; Linn and Petersen, 1986; Lockheed, et al., 1985). When differences do arise, females tend to perform better than do males on some tests of computational skills, while males tend to perform better on items involving problem-solving skills. Overall, mathematical achievement differences often are accounted for by differences in course-taking between male and female students (Chipman and Thomas, 1985). For example, among 1982 graduating seniors, only 35 percent of females, compared to 47 percent of males, have studied four or more years of high school science.

Among those who anticipate science and engineering majors, one-quarter of both men and women initially choose computer science, while proportionally more women than men choose mathematics majors. Data in Table 2 indicate that with the exception of engineering (which favors men) and psychology and social sciences (which favor women), comparable percentages of young women and young men intend to study science in college. Similar patterns are found among gifted and talented women (Fleming and Hollinger, 1979; Hansen and Neujahr, 1974; Wright and Hounshell, 1981). Comparisons by sex and race indicate that black and Asian women are more likely than those of other racial/ethnic groups to choose physical science majors (NSF, 1986). Furthermore, women with physical disabilities also are underrepresented in science-related majors. They tend to be concentrated in social and human services

TABLE 2: Intended Science/Engineering Field of Study of 1984 College-Bound Seniors, by Sex

	Percentage*		
Field	Total	Male	Female
Science and engineering (Total)	100.0	100.0	100.0
Biological sciences	7.9	6.0	10.4
Agriculture	2.5	3.0	2.0
Computer science	24.6	24.0	25.8
Mathematics	2.8	2.4	3.7
Physical sciences	4.3	5.0	3.4
Engineering	30.4	42.5	12.1
Psychology	8.9	2.8	17.8
Social sciences	18.5	14.5	24.8

*May not total 100.0 percent due to rounding.

SOURCE: College Entrance Examination Board, in National Science Foundation, Women and Minorities in Science and Engineering, Washington, D.C.: U.S. Government Printing Office, 1986.

majors that offer poorer employment opportunities than do science and engineering majors (Ruffner, in Hopkins-Best, et al., 1985).

Packaging

Texts, published materials, posters, library books, examples, and exemplars all portray more male scientists and mathematicians and incorporate more of their work. Due to publisher guidelines that ensure that segments of our population are represented pictorially in correct proportions, most texts have 50 percent of illustrations and diagrams showing females and 17 percent depicting blacks. However, the cosmetic changes mask the lack of substantive ones. For example, in the 1985 editions of two popular high school biology texts, 75-98 percent of the cited scientific work described the contributions of men, while women's work was cited 2-4 percent. Table 3 shows how secondary American science texts compare with those of comparable countries. In all cases, science is packaged as masculine. Although fewer illustrations are used in mathematics texts, U.S. publishers conform to the proportional representation. However, the contributions of women mathematicians are seldom cited.

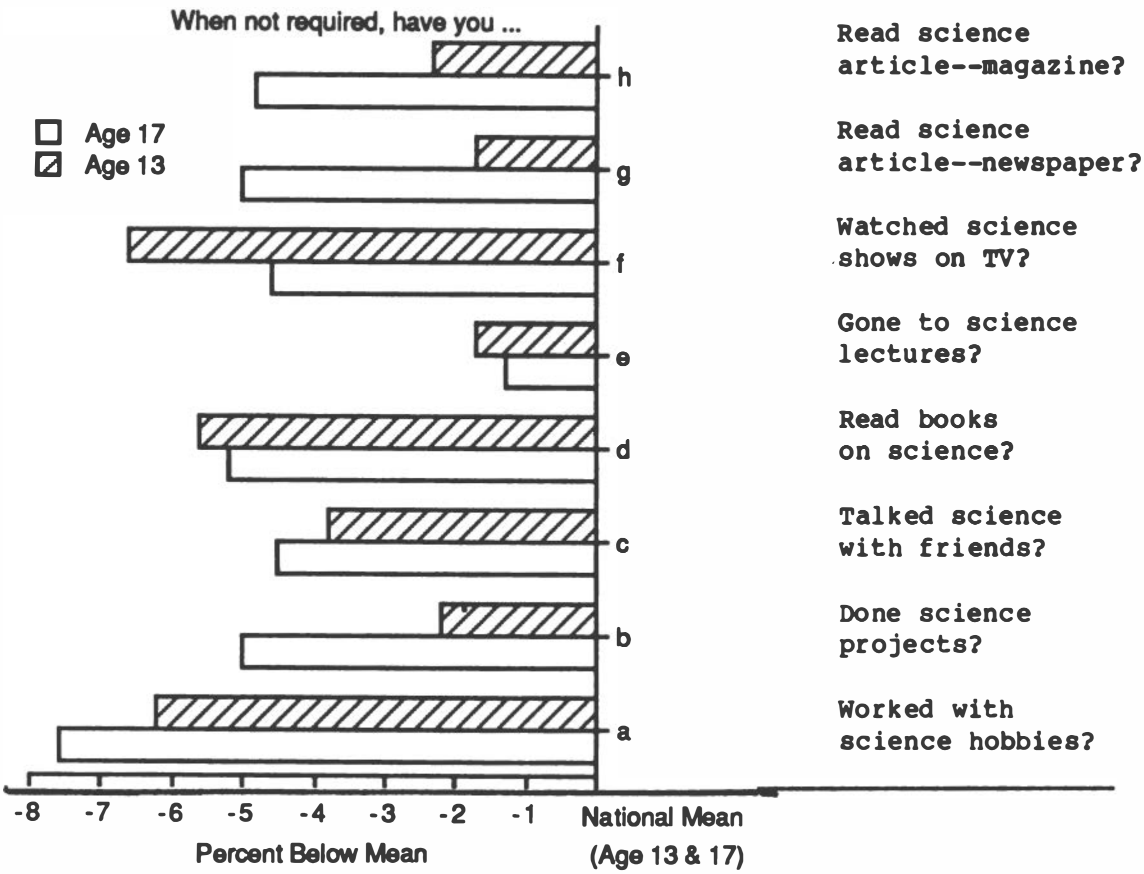
The packaging of science and mathematics outside of schools also leads to masculine images. For example, a lack of role models has often been cited as a reason for the lack of science and mathematics

TABLE 3: Gender Analysis of Illustrations in Science Texts

			Percentages		
Country	Date	Text	Male	Female	Unknown
UK	(unknown)	Nuffield Combines Science (activity books)	78	14	8
UK	(unknown)	Science for the 20's	62	31	7
UK	(unknown)	Science 2000	62	21	17
USA	1983	Holt, Modern Biology	63	30	7
USA	1983	Scott-Foresman, Biology	58	35	7
USA	1983	Merrill, Biology--Living Systems	57	34	9
USA	1985	BSCS, Biological Sciences: A Molecular Approach	51	49	0
USA	1985	Scott-Foresman, Biology	60	32	8
Australia	1981	Fundamental Science, BK 2	85	15	0
Australia	1981	Fundamental Science, BK 3	54	38	8
Australia	1982	Towards Tomorrow	90	10	0

SOURCES: B. Smail, Girl-Friendly Science: Avoiding Sex Bias in the Curriculum, London: Longman, 1984; J. B. Kahle, SCORES: Science Career Options for Rural Environment Students, Women's Educational Equity Action League Report No. GXX 840 2219, Washington, D.C.: The League, 1986; and J. B. Kahle, "The Image of Science," in Gender Issues in Science Education, B. Fraser (ed.), Bentley: Western Australian Institute of Technology, 1986.

interest among young women. Most children encounter few science role models in person during their precollege years. Although the evidence is divided, some studies suggest that the presence of female science or mathematics role models may have an impact on encouraging girls and women to enter science and engineering courses and careers (Casserly, 1979; Fox and Richmond, 1979; Kingdon and Sedlacek, 1982; LeBold, et al., 1983; Weishaar, et al., 1981). Furthermore, it has been suggested that models may be effective whether they are encountered through



SOURCE: Jane Butler Kahle and Marsha K. Lakes, "The Myth of Equality in Science Classrooms," Journal of Research in Science Teaching, 20:131-140, 1983.

Figure 3 Female differences from national mean on items concerning extracuriccular, nonrequired science activities, ages 13 and 17.

written materials, on television, or in person (Eisenstock, 1984; Haas, et al., 1984; Malcom, 1983a; O'Bryant and Corder-Bolz, 1978; Tibbetts, 1975).

In addition, extracurricular activities of school-age children may lead boys and girls to perceive the science or mathematics "package" differently. For example, both NAEP assessments have shown that boys and girls do not participate equally in extracurricular science activities. As early as age 9, girls have less extensive backgrounds in science-related activities than their male peers (Hueftle, et al., 1983; Kahle and Lakes, 1983). Furthermore, the differences increase with age, according to information presented in Figure 3. Notably, gender differences in science activity participation precede later gender differences in science attitudes and achievement (Haertle, et al., 1981; Kahle and Lakes, 1983).

TABLE 4: Teacher Markings of Science Work Attributed to 12-Year-Old Boys and Girls

Teacher Sex	Paper Marks	Student Sex	
		Male	Female
Male	High marks	6	2*
	Low marks	11	19*
Female	High marks	30	7*
	Low marks	3	12*

*p = 0.1

SOURCE: M. G. Spear, "Sex Bias in Science Teachers' Ratings of Work and Pupil Characteristics," European Journal of Science Education, 1984, pp. 374, 375.

Practice

Today teachers typically hold higher general academic expectations for male students than for female students (Clifton, et al., 1986; Eccles, 1984). In mathematics, sex differences in teacher expectations are not always found, but when they are present, they favor boys (Eccles, 1985; Wilkinson and Marrett, 1985). One experimental study, shown in Table 4, asked science teachers to evaluate samples of students' work (Spear, 1984a, b). When teachers believed that the work had been done by a boy, it was judged more scientifically accurate, better organized, richer in ideas, and more concise than when the work was attributed to a girl. Papers attributed to girls were judged to be neater than those assigned to boys.

Furthermore, when teachers are asked to identify scientifically talented or gifted students, a cross-cultural pattern emerges. Both Australian and American teachers identify more boys. When observers record both the number and duration of teachers' interactions with the identified creative girls and boys, they find that teachers interact twice as often with the boys and for longer durations. According to Gordon and Addison (1985), when teachers nominate students for special programs, boys of average abilities are nominated before gifted girls. As Casserly (1979:349) stated:

> Too often in the school, the behavior that is evidence of "critical thought and a questioning mind" in a young man becomes evidence of "insolence" and an "argumentative nature" in a young woman . . . gifted young women are particularly adept (often to their disadvantage) at living up to the expectations of others and no more [sic]. Well-

> adjusted, pleasant, young ladies don't make waves or they're suddenly seen as "aggressive" or worse. Young men who suddenly demand challenging work are seen as finally settling down and getting serious about life and their future careers.

On the other hand, minority and physically disabled females today are in a double bind. Teachers' expectations of minority females are influenced by both race and gender (Malcom, et al., 1975), while female students with disabilities are frequently perceived as "dependent, helpless, vulnerable, and subservient" (Hopkins-Best, et al., 1985).

Unfortunately, teacher expectations influence the behaviors of both teacher and student (Eccles, 1984), and they may affect students' science and mathematics achievement (Crano and Mellon, 1978; Spear, 1984a, b). Secondary and elementary teachers, on the average, interact more with male than with female students, especially in mathematics and science (Eccles, 1985; Sadker and Sadker, 1985; Webb, 1984). In the course of one year, elementary-aged boys, compared with girls, in one study received six more hours of one-on-one mathematics instruction (Leinhardt, et al., 1979). Taken over the course of elementary school, 36 hours of individual mathematics instruction may have important effects on a student's interest, achievement, and self-confidence.

In both science and math classes, the largest gender differences in student-teacher interaction appear during "whole class interaction" (Tobin and Gallagher, 1987; Tobin and Garnett, 1986), such as question-and-answer or discussion sessions. At all precollege levels, boys are called on more often than girls are (Sadker and Sadker, 1985; Tobin and Garnett, 1986; Webb, 1984), especially when higher-order cognitive questions are involved (Tobin and Gallagher, 1987; Tobin and Garnett 1986). Today, cooperative learning settings, including laboratory work, account for only a small portion of time in secondary science classrooms (15 percent). The majority of time is spent either in lecture (23 percent) or in whole class interaction such as question-and-answer sessions (33 percent) (Tobin, 1986). In mathematics, boys, compared with girls, prefer competitive rather than cooperative activities that are frequently used in schools (Lockhead, 1984; Peterson and Fennema, 1985). The perception that science and mathematics are masculine is reinforced by classroom practices and teacher behaviors. For example, boys are allowed to dominate discussions and equipment and are four times more likely to be target students than girls are in science and mathematics classes (Tobin and Garnett, 1986). The actual practice of mathematics and science today as factual knowledge, presented by whole-class instruction and related to male activities, is an anathema to girls both at the elementary and secondary levels.

Although not directly part of the student-teacher interaction pattern, counselors and parents also affect the practice of science. Regarding high school, large-scale studies in the 1970s indicated that counselors tend to hold gender-biased attitudes (Ahrons, 1976; Donahue and Costar, 1977). Furthermore, college science majors ranked their high school counselors last (after biology teachers, parents, and other teachers) when asked who had influenced their choice of major

(Kahle, 1983b). Other studies suggest that both minority and majority girls perceive high school guidance personnel as either a negative or neutral influence on their decision to study science or engineering or to participate in special programs (Casserly, 1979; Malcom, et al., 1975; Matyas, 1983).

Biological Factors

Recently, research has addressed the most difficult of the four factors to assess; that is, the relationship of science's and mathematics' masculine images to the purported higher aptitudes and abilities of boys for science and mathematics. Differences in boys' and girls' scores on tests of spatial ability have been attributed to an inherited characteristic, yet Kelly, et al. (1984), have shown that the difference between girls' and boys' spatial ability scores are eradicated when girls enroll in just one technical trades course. Furthermore, Linn and Petersen's (1986) recent review of the research concerning spatial ability reports no evidence that sex differences in spatial ability explain gender differences in mathematics performance.

Benbow and Stanley (1980) and Benbow (1986) found consistent sex differences in mathematical reasoning ability (as measured by the SAT-Math) among intellectually talented 12- to 13-year-olds. The difference favors male students (Benbow, 1986). They suggest that this difference reflects innate abilities and Benbow's recent study suggests that differences in hormonal levels are involved. However, Benbow and Stanley's methodology and conclusions have been questioned by several researchers (Eccles and Jacobs, 1986; Fox, 1984; Pallas and Alexander, 1983; Stage, 1986).

Furthermore, Stage (1986) has refuted the recent claim that male and female math and science ability differences are due to different levels of fetal testosterone. She reports, rather, that studies have revealed that high levels of fetal testosterone in boys may lead to a higher incidence of left-handedness, immune disorders, dyslexia, and other learning disabilities. On the other hand, high levels of fetal testosterone in girls may lead to "tomboyishness" and increased spatial ability. Clearly, we must look beyond biology to the social milieu to find factors related to the masculine images of science and mathematics.

Transition from Actual to Ideal State

> [B]oys and girls enter school science classrooms with different past experiences, different interests, different attitudes, and different expectations. This indicates that teachers cannot dismiss the problem of girls' under-achieving in science by treating boys and girls identically. . . . [T]he science classroom and curriculum are designed to build on a foundation of interests, experience and attitudes that is present for one sex but not for the other. Treating boys and girls identically in school can serve to accentuate

Ideal	Actual
Gender neutral science	Masculine science
Women are viewed as an integral part of the scientific community by colleagues, educators, students, and the general public	Science is viewed as a masculine domain by the scientific community, students, and the public
Low female attrition from elective science/math courses	High female attrition from elective science/math courses
Both male and female students work up to full potential in precollege science/math	Gender differences in precollege science and math achievement
Science is taught by both men and women	Science classes are primarily taught by men
Students feel free to choose college majors and careers according to their interests and abilities	Students follow sex stereotypes in addition to perceptions of abilities and interests in choosing a major/career
Nonsexist texts and instructional techniques such as discussions and laboratories that maximize learning for all students	Sexist curricula and whole class instructional techniques that benefit selected groups of students
Expectations of student abilities, interests, and performance are unrelated to student sex, disconfirming societal stereotypes	Teacher, counselor, parent, peer and the student's own expectations are biased by sex-role stereotypes
Institutions are committed to addressing the special needs of gifted and disabled females	Gifted and disabled females are often not encouraged to fulfill their potential in science/math
Transformation of student's views of sex roles through science classes	Traditional sex roles reinforced by science classes

Figure 4 A contrast between the ideal and the actual state of science education.

> rather than diminish the existing differences. (Johnson, 1984:22)

A summary of the actual and ideal states of science education in Figure 4 reveals 10 basic areas of difference, while a review of intervention projects indicates ways to change from the actual state to the ideal state. Many of the prerequisite changes have been discussed in the "Ideal" section; others will be proposed now, based on the premise that changes in the practices and packaging of science and mathematics will diminish their masculine image. As the image becomes more accurate, the numbers of girls participating and achieving in science and math will increase, and science and mathematics classes will transform, not reproduce, society's stereotypic vision of those disciplines. As Alison Kelly has said,

> [T]he masculinity of science is an <u>image</u> (author's underscore). Whether it is caused by textbook representations or by classroom behaviors, it is essentially a distortion of science. The word 'image' is linked to 'imaginary' and these three mechanisms all suggest that the masculinity of science is only an illusion, not an intrinsic part of its nature. (1985:146)

But how does one affect packaging and practice? One of the most efficient and effective mechanisms is through teacher education, both in-service and pre-service. Several in-service projects suggest the ideal in mathematics and science education. Do they also suggest what type of teacher training works? A close examination indicates that they do. For example, the results of the GIST project were limited, partly, because the teacher-participants did not "buy in" to the program (Smail, 1985). It also emphasized careers and interests, rather than directed intervention and skill development, described in the more successful studies.

Teacher Education

A recent U.S. project, designed as an attempt to forge a link between actual and ideal science teaching and practices, also produced limited results (Kahle, 1986a). This project ignored the issues of sex-role stereotyping of careers, sex-linked patterns of course selection, and sex-role socialization in schools. Rather, it focused on career information, role models, and interest-oriented materials. When the results were in, it was found that boys, compared with girls,

- Had more experiences in science,
- Indicated higher interest in science careers,
- Held more positive perceptions of science and scientists,
- Expressed more positive attitudes toward science and scientists,

- Found science more useful, and
- Received significantly more A and B grades in science.

The indirect, interest-oriented approach for in-service teacher education did not work. Results of Rennie, et al. (1985), on the other hand, suggest that a direct approach works. As they stated, their western Australian project

> . . . worked explicitly to change teachers' attitudes and behaviors and appears to be successful in this. . . . [M]oreover, . . . the changes in the teachers appeared to be associated with corresponding changes in the students. (p. 143)

Furthermore, Parker (1985:16) discussed why the route of "interest-based science" will not lead to equitable science education:

> If the teachers . . . had based their programs on students' expressed or expected interests, then the girls concerned would never have experienced working with electricity, and would never have been given the opportunity to find out whether they had a liking or an aptitude for the area.

The educational pathway, therefore, must be direct, explicit, and sustained and meet the actual requirements for further education in the sciences. Projects focused on interests and careers, often involving female role models, may create the desire to do science, but not provide the prerequisite skills.

Both the in-service and pre-service education of primary teachers requires fundamental changes that will provide them with an understanding of the processes of science and with successful strategies for teaching science. The problem is two-fold: first, teachers have inadequate scientific backgrounds and, second, they are uncomfortable with small-group interactions. Fensham[1] suggests that whole-class instruction involving everyday science phenomena is needed in the transition period from actual to ideal. Teachers, more comfortable with whole-class teaching, may use it to investigate with their students phenomena that they can observe, and test, within their classrooms. For example, what level of lighting is actually needed? Why do the plants bend toward the window? What is the mean, mode, and range of student heights? How does a thermostat work? In this way, they can build the confidence and skills needed to implement the "hands-on" curriculum.

Other changes in the practicing of science will occur in schools and classrooms. An initial step is for schools to review the range of subjects offered and monitor the pattern of choices made by boys and

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[1]Private communication between Jane Butler Kahle and P. J. Fensham, Melbourne, Australia, September 15, 1986.

girls (Yates, 1986). In that way they can identify problems and target changes. In addition, the ideal state will only be reached when science and math are taught as they are practiced--that is, in mixed groups. Although the transition period will need well-trained women from single-sex schools, long-term gains must be made in coeducational classes, in which discussions and laboratories provide time for tinkering and for sharing as well as an atmosphere conducive to trial and error and to risk-taking. In such settings, boys can learn to respect the ideas of girls and to work with them as equals. In the transition period from actual to ideal, boys, who hold stronger sex-stereotyped opinions than girls do, may be the target of intervention programs.

Research

Another pathway from the actual to the ideal state will explore new types of educational research. For example, extensive experimental, or at least longitudinal studies, are needed to confirm the correlational relationships found in today's research. Since successful intervention programs can provide a useful source of experimental data, it is important that funding in this transitional stage include monies for evaluation as well as for implementation. In addition, the lack of research on minority, gifted, and disabled girls and women must be addressed. The ideal state of science and mathematics education will need data to determine how minority status, giftedness, and physical disability influence the mathematics and science education processes for women and for men. Without that information, the ideal state will be valid for only a shrinking portion of the precollege population.

The importance of research in reaching the ideal state is dramatized by the situation today. In 1984, a National Science Teachers Association survey requested science teachers to rank areas of research in order of interest. The following five areas received the highest rankings: laboratory experiences, motivational techniques, effect on college courses, problem solving, and meaningful learning. All of them represent areas in which gender differences have been found. Yet of the 23 research areas listed in the survey, research in the area of sex differences was ranked last by the teachers surveyed (Gabel, et al., 1986). In the transition period, researchers concerned with gender issues must do a better job of discussing their work and findings with teachers and parents.

Curriculum

A third route from actual to ideal educations in science, mathematics, and engineering requires changes in the packaging of science and math materials. Science and mathematics textbooks must continue to evolve from adding illustrations of girls to describing work of women scientists in paragraphs set off (and frequently boxed) from the text to restructuring the presentations of science and mathematics so that they are relevant to girls as well as to boys. However, the curricular path should not lead to separate and unequal science and mathematics curricula for young women.

Parent Education

Fourth, because of the important influence parents have on their daughters' science and math interests and achievement, strategies for educating parents must be explored. Some formal efforts have begun--for example, the Family Math Program developed at the Lawrence Hall of Science. Other, more informal activities have been designed into intervention programs (Kahle, 1986b). In the transition period, projects such as the collaborative one between the College Board and the American Association for the Advancement of Science to develop booklets, which both describe the importance of science and math and delineate ways parents can assist their children in science and math, are important.

Summary

The four routes described above all lead from today's to tomorrow's education in science and mathematics. Collectively, they will change the practice and packaging of science and math as well as the numbers of girls and women studying those subjects. As those three aspects change, the images of science and math will become more realistic. Although there is neither a quick nor an easy route, a focus on all levels of precollege education will speed the process. A revolution in science and mathematics education will result in the evolution of science and math and, in the process, their public images may be improved.

The paths proposed in the transitional period from actual to ideal follow the directions identified by projects and by teachers successful in promoting science and mathematics education for all. However, education in math and science is at a crossroads. The path to the left follows today's practices and results in some boys and a few girls studying science and mathematics. But the path to the right leads to increased numbers of boys and girls studying science and mathematics and thereby prepared for earning and living in tomorrow's technical society.

In conclusion, the words of a 15-year-old girl dramatize why choosing the road to the left is making a wrong turn (Kahle, 1986b):

> Interviewer: What is your image of a scientist?
>
> Susan: A scientist's totally involved in work. Therefore, they don't care about appearance. [They] wear white coats, have beards--'cause they're men. They just seem to care only about their science work. . . . They don't care about meals. Somedays they starve themselves. They walk around with their science brain all day, and they've got their laboratories.

Interviewer: What do you want to do?

Susan: Be able to help people. Not like a scientist or a doctor or anything like that. But help their mind [sic]. I want to be a psychologist. I want to help people that [sic] need it.

I'm hoping to study psychology when I get to uni[versity] and that is probably what I'll be. But I'd also like to be a racing car driver and to fly planes. But you have to do physics to be a pilot, . . . I don't want to do that.

Interviewer: What about psychologists? Are women psychologists?

Susan: I think there's more women. Because, I mean, people tend to see men and women in different roles even now. They still do. And women are the people that [sic] care. They help you sort out your problems and things like that. And men are the brains, and they just are totally on facts. And they're there to work out the hard things in the world.

Interviewer: Are men smarter?

Susan: No.

Interviewer: How are you using the term, "brains"?

Susan: They're not smarter, but people see . . . [that they] are. Society today considers men smarter than women. Therefore, they are going to get the jobs over women. . . . They're the ones you see with the brains, but you don't see [women], because people don't hire them as much.

Although the societal and cultural changes needed to modify Susan's perceptions will require time and substantive restructuring, the effect of equitable education may be immediate. For example, Susan must realize that psychology is a science, which requires that she study mathematics, and she as well as all children need to keep their options open. Perhaps, however, the greatest effect of equitable education in the sciences and mathematics will be equal opportunities for both girls and boys (or women and men) to "help people" and "to sort out the hard things in the world."

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DISCUSSION: EQUITABLE SCIENCE AND MATHEMATICS EDUCATION

Susan F. Chipman

In attempting to understand what causes the differences between men and women with respect to their participation in mathematics, science, and engineering, Kahle and Matyas--and all of us--address a very complex situation. Their paper discusses many factors in precollege education that plausibly could have some influence on the representation of women. Many points of difference between male and female students and the way that others treat them are described and documented.

If we are to either gain real understanding or have a basis for deciding where leverage can be placed in order to effect change, we need to organize all of this information with a dynamic theoretical model of the processes determining individual lives. That is, we need to approach this problem as a scientific problem in its own right. We must use a theoretical model to guide our research and data analysis efforts so that we can begin to determine which of the many plausible variables are actually important and to understand how they act and interact. How do all these variables act on individual life decisions?

In an earlier paper (Chipman and Thomas, 1984) for a National Research Council committee, I attempted to formulate a reasonably comprehensive and general version of such a model. It was based on a theoretical approach that others (Casserly and Rock, 1985; Eccles-Parsons, et al., 1983; Lantz and Smith, 1981) had taken to understand the case of female participation in high school mathematics courses.

As Figure 1 illustrates, the outcome--participation--is understood as being influenced by two major factors: expectancy of success and value assigned to the outcome. Each of these, in turn, has many contributing determinants, as shown in Figures 2 and 3. Expectancy of success is likely to be influenced by such factors as cognitive ability--in which there are important individual differences and in which some claim that there are relevant sex differences (Benbow and Stanley, 1980). Confidence in one's ability--an area in which large sex differences are found--also affects expectancy. General stereotypes of the abilities of particular population groups might affect their expectancy of success, either directly or through an effect on their confidence.

The value of participation in a particular field of endeavor is also subject to many influences of the sort that Kahle and Matyas

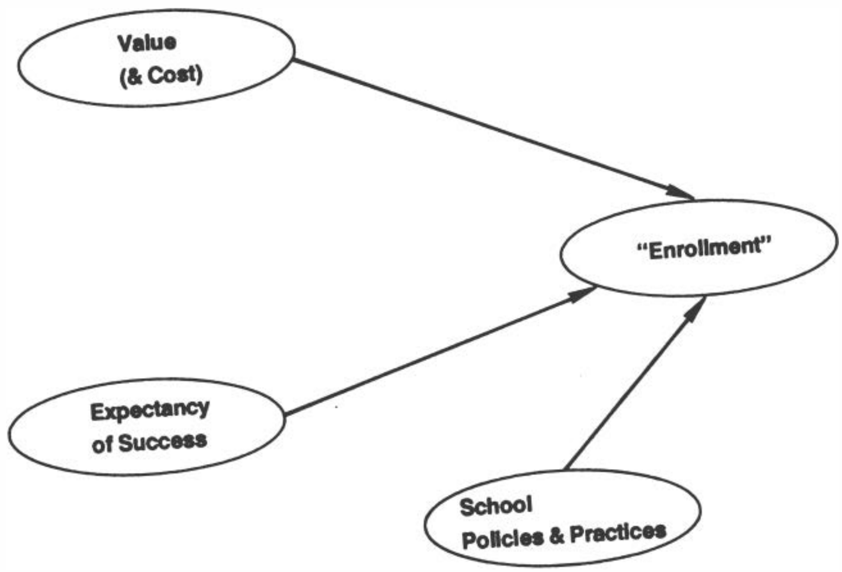

Figure 1 Core of the model.

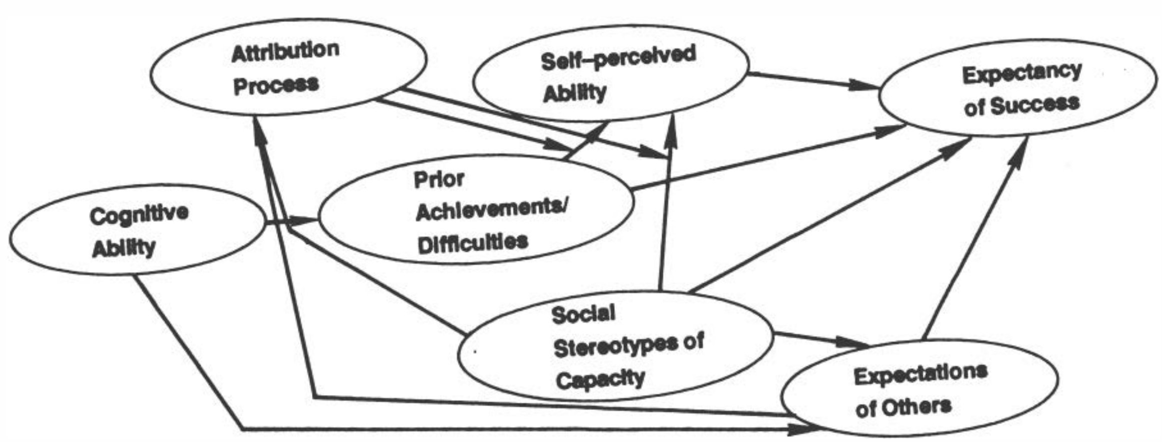

Figure 2 Influences on expectancy.

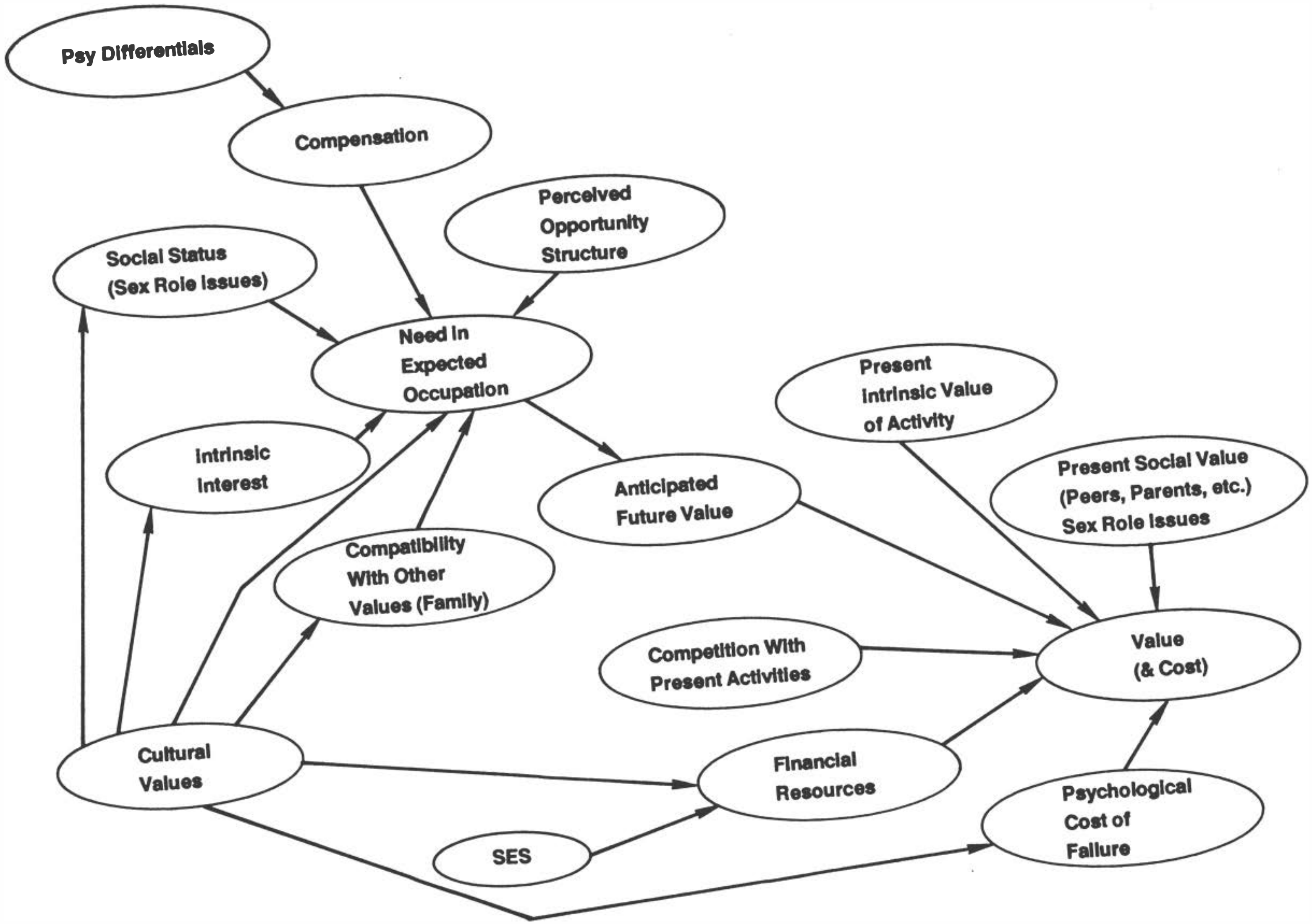

Figure 3 Influences on value.

describe. Immediate reinforcement or lack of reinforcement for participation may be important, as coming from parental encouragement, the expression of negative attitudes by male peers, or generally prevalent stereotypes of social suitability. The anticipation of future family-career conflict fits in here. (I must point out that this perception may well be valid: those who are scientists, who work with scientists, and who study scientists know that successful scientists typically work extremely hard and extremely long hours--well beyond the 40-hour work week.) The expectation or lack of expectation that long-term rewards will be available in the form of employment opportunities and fair compensaton is another potentially important factor. Finally, individual global interest patterns (which Kahle and Matyas did not discuss in a serious way) clearly influence the perceived value of career and courses of study and have substantial effects upon the selection of scientific careers. Furthermore, there are large sex differences in these interest patterns that can account for much of the sex difference in career selection (Dunteman, et al., 1979), and such interest patterns are established at a very early age (Tyler, 1964).

Unfortunately, with only two or three exceptions, research to date does not demonstrate that the vast majority of these variables are actually important in determining the outcomes of interest, nor, of course, has it provided us with quantitative measures of relative importance. For individuals, it is clear that cognitive ability is an important predictor of persistence in mathematical, scientific, and technical fields, but it is rather unlikely that sex differences in ability contribute significantly to the observed sex differences in participation. In contrast, basic interest patterns--such as the relative interest in things versus people--are also significant predictors for individuals and provide a possible account for much of the observed sex differences in participation. More research attention needs to be given to the early development and possible determinants of those interest patterns. It is possible that confidence in ability --which varies somewhat independently of actual ability--also provides some of the explanation for observed sex differences in participation. More attention needs to be given to understanding the relationship between actual and perceived ability and their mutual relationships to continued participation. Most of the variables discussed by Kahle and Matyas probably have small effects on either expectancy of success or the value of participation. By focusing on the points where such variables would be expected to have their most direct effects--something that has not been done in past research--it may be possible to measure those small effects (see Chipman and Wilson, 1985, for a relevant discussion of the above points in the context of female participation in mathematics).

It seems obvious that experimental efforts at intervention should focus on those few variables shown to have significant effects. Otherwise, to have any hope of effect by altering variables, which at best have small effects, one would have to have an extremely broad-based intervention, broader than is likely to be practical. As an example of intervention that makes sense given research results, minority participation in mathematical, scientific, and technical fields undoubtedly can be improved most effectively by concentrating on improving achievement in the early school years. It is not obvious that it is still possible to change the basic interest patterns that are most relevant to female participation at the relatively advanced ages, where interventions are normally attempted. Indeed, it is not obvious how they can be changed by intervention at any age. It is probably worthwhile to attempt to experimentally alter the confidence of female students in a positive direction.

In closing, I would like to comment on the presumption that underlies the paper that Kahle and Matyas have written, as it underlies most discussions of this kind: the presumption that the desired goal is perfectly even representation of every identifiable population group in every occupation. Should that, indeed, be our goal? If the choices that we observe are found to reflect individual and cultural differences in values--rather than arbitrary discriminatory barriers or discouraging treatment--should we regard that as a problem? Is it in any way appropriate to attempt to modify those values?

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WOMEN IN ENGINEERING AND SCIENCE: AN UNDERGRADUATE RESEARCH PERSPECTIVE

William K. LeBold

Introduction

A variety of sources have been used in developing this paper, including a comprehensive analysis of statistical data on the characteristics and education of scientists and engineers and the related literature. Primary attention has been given to data and literature related to and within the various engineering and scientific disciplines, especially those where women are underrepresented at the undergraduate level (e.g., engineering, physical science, and computer science). Comparative data and information in areas where women are almost equally represented at the undergraduate level (e.g., psychology and health science) are presented but are not the primary focus of this document. This paper focuses on these major objectives:

- To identify the areas of engineering and science in which women are underrepresented in undergraduate education;
- To identify the factors contributing to that underrepresentation;
- To identify and to compare the factors associated with attrition and retention rates of men and women in undergraduate science and engineering education programs;
- To examine the factors influencing women's decisions to attend graduate school in engineering and science, including the impact of financial aid and other sources of support;
- To examine policies and practices that may influence the differential enrollment of women and men in undergraduate and graduate engineering and science programs; and
- To identify areas of future research needed to better understand the factors associated with the underrepresentation of women in science and engineering.

Although theoretical perspectives and empirical research will be examined, major attention is focused on presenting the key data regarding the underrepresentation of women in science and engineering, examining the factors influencing their underrepresentation and identifying policies and practices that reduce inequities in the representation of women in science and engineering.

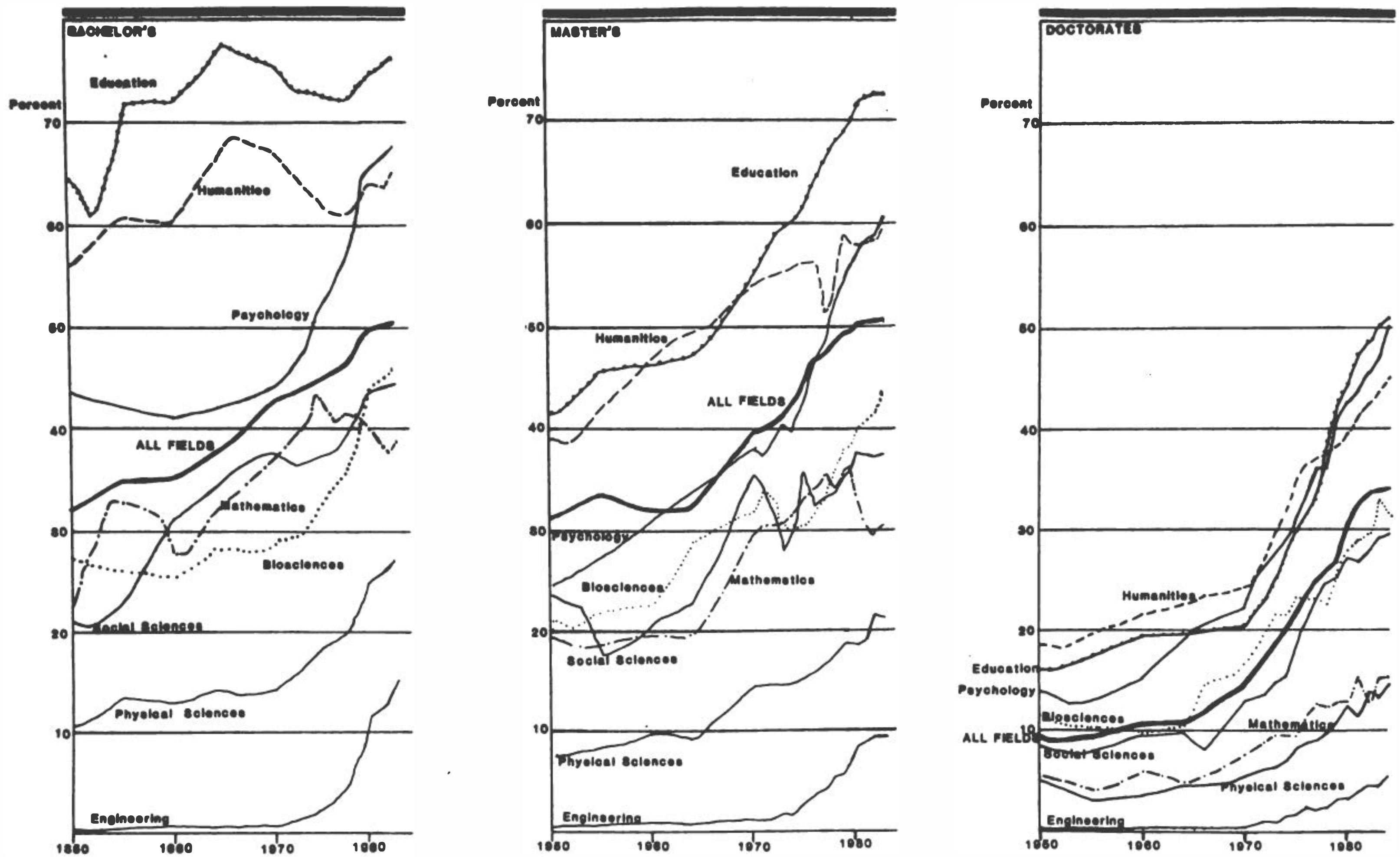
Underrepresentation of Women in Engineering and Science, by Field

Degree Data

The 1986 biennial report of the National Science Foundation (NSF) to the U.S. Congress, Women and Minorities in Science and Engineering, indicated that in 1984 there were 3,995,500 engineers and scientists in the United States, including 1,781,400 scientists and 2,214,000 engineers (NSF, 1986b). These figures reported 512,600 women engineers and scientists (12.8 percent of the total) including 438,100 scientists (23.9 percent) and 74,500 engineers (3.4 percent). Hence, even if parity (50 percent men and 50 percent women) were reached in the coming decade, it would be well beyond the year 2000 before employment equity in science and engineering might be reached or even approximated. On the positive side, it is important to note that very significant strides have been made by women in the United States during the past two decades. Women in 1984 constituted 51.3 percent of the U.S. population and 43.7 percent of those employed in the United States. In early 1984, more women (52 percent) were attending higher educational institutions in the United States than men, comprising 52 percent of the undergraduates, 53 percent of the freshman, and 48 percent of the graduate students (Chronicle of Higher Education, January 22, 1986).

Although beyond the scope of this report, it is important to note that the data presented in this report are based on enrollment and degree information from U.S. educational institutions. Relatively large numbers of engineers and scientists in the U.S. work force do not have U.S. degrees in science and engineering; many engineers and scientists have either degrees in other disciplines or degrees from other countries, and many engineers and some scientists have no formal degree of any kind. Estimates of the numbers of scientists and engineers in the United States vary considerably, depending on the data sources used and the definitions employed. Estimates for 1984 vary from almost 4 million (NSF, 1986a) to the less than 2.5 million reported in the latest report of the Bureau of Labor Statistics (1986).

There are wide differences in the degree to which women are represented in various engineering and science fields. Figure 1 provides an excellent perspective for examining the trends and differences in the rates of their participation. At the bachelor's and master's degree levels, women reached equity (50 percent) in all fields in the 1980s, but remain largely underrepresented at the doctorate level. However, the overall bachelor's and master's equity levels are due largely to the overrepresentation of women in education and the humanities and approximate parity in psychology and the social sciences. Underrepresentation of women at the bachelor's degree level is exceptionally prevalent in engineering (14.5 percent in 1985) and in the physical sciences (less than 30 percent in 1985). At the master's level in 1985, there was even lower representation of women than at the B.S. level in most fields: underrepresentation was again especially critical in engineering (11.4 percent) and physical sciences (under 25 percent); in mathematics and social sciences, less than



SOURCE: Betty M. Vetter and Eleanor L. Babco, eds., Professional Women and Minorities: A Manpower Data Resource Service (6th ed.), Washington, D.C.: Commission on Professionals in Science and Technology, February 1986.

Figure 1 Trends in the percentage of degrees awarded to women, by degree level and field, 1950-1980.

40 percent of the degrees were awarded to women, but in the biological sciences women rapidly approached the 50 percent level. However, representation of women is above or at parity in education, the humanities, and psychology.

The most serious inequities in the representation of women occur at the doctorate level, where parity has only recently been achieved in education and psychology but is rapidly approaching it in the humanities. The gross underrepresentation of women at the doctoral level in engineering (5.7 percent), in physical sciences (less than 15 percent), and in mathematics (less than 20 percent in 1985) is especially significant. These areas represent fields that are of increasing importance nationally and internationally. Those holding doctoral degrees in engineering, physical sciences, and mathematics are most likely to have major responsibility for basic and applied research in academic institutions, for key research and development roles in high technology industries, and for public works projects supported with federal funds.

To provide a more detailed perspective by disciplines within fields, a variety of data sources are available, including those supported by the National Science Foundation, U.S. Department of Education, U.S. Department of Labor, Engineering Manpower Commission, College Entrance Examination Board, American College Testing Service, and American Council on Education. Fortunately, the Commission on Professionals in Science and Technology (formerly the Scientific Manpower Commission) has performed the Herculean task of compiling information from a wide variety of sources as part of its manpower data resource service, which publishes annually Professional Women and Minorities (Vetter and Babco), the standard data reference on women and minorities in science and engineering. Between annual editions, the Commission also publishes Manpower Comments, which provides a periodical digest and selected new data in regard to the supply, demand, and educational utilization of scientists and engineers (including information on women and minorities). These data sources not only provide a contemporary perspective, but also document particular trends over the past two decades as well as general trends over the past 50 years.

Data compiled by the Commission on Professionals in Science and Technology[1] indicate that by 1982-83 over half of the bachelor's and master's degrees awarded in the United States were earned by women. At the bachelor's level, women received over half of the degrees awarded in the health sciences (70.3 percent) and psychology (67.5 percent) and were approaching parity in the biological sciences (46.1 percent). However, while the percentage of bachelor's degrees awarded to women in some science and engineering areas has increased during the past decade, they remain significantly below parity: computer and information science (36.3 percent), physical science (27.3 percent), and

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[1]See U.S. Department of Education, National Center for Education Statistics, Earned Degrees Conferred series (1948-1981), and National Research Council, Doctorate Recipients from U.S. Universities: Summary Report (1970-1983).

engineering (13.3 percent). The only areas having a lower percentage of bachelor's degrees awarded in 1982-83 were engineering technology (8.0 percent) and military science (10.9 percent).

Beginning College Data

To provide early time perspectives on current and future trends regarding the representation of women in science and engineering, excellent data are available on the educational and career plans of college freshmen [from the joint studies of the University of California, Los Angeles (UCLA) and the American Council on Education (ACE)] and of college-bound high school seniors (from the Educational Testing Service's College Entrance Examination Board). Data on probable major field of study of college freshmen in all U.S. institutions of higher education (see Table 1) document the trends, as well as the significant gender differences, in the educational plans of college freshmen. ACE data on probable career plans reflect similar gender differences (see Table 2, pages 58-59). These data sets clearly indicate the major factor underlying the underrepresentation of women in science and engineering: college-bound women do not plan to major or have careers in engineering and the physical sciences in the same proportions as college-bound men.

There has been some increased interest among college-bound women and freshmen in engineering and science fields and careers, but the changes have been relatively small in the 1980s and have even declined in some areas (engineering and physical science) in recent years. Near parity exists in biological sciences and most business-related fields, but women beginning college continue to be more interested than men in pursuing undergraduate education and later careers in the arts. Physical science, mathematics, computer science, and engineering continue to appeal to about three times as many beginning college men as women, with engineering representing ratios of about 6-1 in 1985 (a significant change from the over 50-1 ratios of 1971) and physical science with ratios of about 3-1 (up from the 5-1 ratio of 1971). Mathematics and statistics are very close to equal representation at the freshman level; and in the rapidly growing computer science and systems analysis fields, ratios of about three men to two women characterize the contemporary freshman scene.

Detailed Field Differences

The data previously presented clearly indicate that the major fields in which women are underrepresented at the undergraduate level are in engineering and physical sciences.

<u>Physical Science.</u> Table 3 (page 60) presents information on B.S. degrees in physical sciences by field including detailed data for astronomy, biochemistry, chemistry, geological and earth sciences, and physics from 1971 through 1983. These data indicate that underrepresentation of undergraduate women is especially high in physics, where only 1 in 8 of the B.S. degrees in 1983 was awarded to women (up from

TABLE 1: Percentage Distribution of Freshmen, by Probable Major Field 1971-1984

Probable Major Field of Study	1971 Men	1971 Women	1973 Men	1973 Women	1975 Men	1975 Women
Agriculture/forestry	5.4	0.7	4.4	1.0	5.7	1.9
Arts and humanities*	16.8	20.5	10.1	15.0	12.7	12.8
Biological sciences	4.4	2.7	8.2	5.7	7.1	5.5
Business	18.3	14.2	21.1	14.0	20.1	17.5
Education	4.6	15.9	5.2	19.6	4.6	15.5
Engineering	13.2	0.3	12.1	0.7	14.0	1.3
Health professions (non-M.D.)	2.6	16.1	4.6	16.5	1.8	13.2
Mathematics/statistics	2.6	2.9	1.8	1.6	1.1	1.1
Computer science	--	--	--	--	--	--
Physical sciences	3.1	0.8	4.2	1.1	4.0	1.3
Premedical, Predentistry, Preveterinary	--	--	--	--	--	--
Social sciences*	5.6	12.2	5.5	11.7	3.7	8.9
Other fields (technical)	7.3	2.6	8.4	2.0	10.3	6.7
Other fields (nontechnical)	1.4	5.0	7.1	3.5	10.2	8.8
Undecided	2.3	2.3	4.5	4.9	4.6	5.5

NOTE: Totals may not equal 100% due to rounding.
*Political Science is included in Arts and Humanities through 1975; in

SOURCE: American Council on Education, The American Freshman: National Research Program, University of California, 1971-1985. Comparable data

1 in 16 in 1971). In 1983 about 1 in 4 B.S. degrees was awarded to women in astronomy and geophysics (up from about 1 in 12 and 1 in 8, respectively, in 1981) and about 1 in 3 in chemistry (up from about 1 in 5 in 1971).

Mathematics, Computer Science, and Statistics. In the quantitatively-oriented science fields, participation rates for women are somewhat higher than in the physical sciences. Table 4 (page 60) indicates that in 1983 the proportion of women receiving bachelor's degrees in computer science was more than twice as high (36.3 percent) as in 1971 (14.6 percent), and the women's share of bachelor's degrees in mathematics increased from 38.2 percent in 1971 to 45.7 percent. For the same period, the number of B.S. degrees awarded to women in statistics was very close to parity (48.7 percent), having almost doubled since 1971 (25.3 percent).

Engineering. Detailed data on bachelor's degrees in engineering fields for selected years between 1971 and 1983 (see Table 5, pages 62-63), of Study in All Institutions of Higher Education, for Selected Years,

1978		1980		1982		1983		1984	
Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
4.5	2.0	4.1	1.8	3.8	1.4	2.9	0.9	3.3	1.0
7.4	10.6	6.4	10.1	6.8	9.7	6.8	9.0	6.6	8.8
4.8	4.4	3.7	3.8	3.7	3.8	4.1	3.4	4.1	4.2
25.0	23.1	22.9	24.5	22.3	25.7	22.7	26.0	25.1	27.5
3.3	12.1	3.3	11.6	2.4	9.0	2.9	8.9	2.8	9.6
18.8	2.3	21.0	3.2	22.3	3.6	20.6	3.5	20.1	3.0
2.0	14.6	1.9	13.3	1.6	17.8	2.1	14.9	2.3	13.8
1.1	0.8	0.7	0.6	0.6	0.7	0.8	0.8	0.8	0.9
1.6	1.2	2.7	2.4	4.9	4.0	5.4	3.7	4.3	2.7
3.5	1.3	3.6	1.6	2.6	1.0	2.5	1.0	2.5	1.1
4.0	2.9	3.6	3.2	3.2	3.0	3.3	3.2	3.2	3.1
5.0	9.5	4.5	8.6	4.2	7.2	4.2	7.6	5.1	8.4
7.0	2.0	8.5	2.9	9.7	4.3	9.9	3.8	7.7	2.4
8.1	7.9	9.3	6.9	8.2	3.3	8.1	7.1	8.0	7.6
3.9	5.3	3.8	5.5	3.7	5.5	4.0	5.7	4.1	6.2

Social Sciences after 1975.

Norms, Los Angeles: Office of Research and Cooperative Institutional
is available from the College Entrance Examination Board.

indicate that women in engineering are most likely to be underrepresented in aeronautical, electrical, mechanical, and mining engineering, where about 1 in 10 B.S. degrees was awarded to women in 1983 (up from about 1 in 100 in 1971) compared with about 1 in 7 overall. The highest representations of women in major engineering fields in 1983 were in chemical, industrial, and metallurgical engineering, where they were awarded about 1 in 4 B.S. degrees (up from about 1 in 50 in 1971-1975).

More detailed information on engineering enrollments (see Table 6, page 64) is presented to illustrate ways in which the data may be used to predict future degree output. Table 6 provides data on first-, second-, third-, and fourth-year undergraduate enrollments and numbers of B.S., M.S., and Ph.D. degrees awarded. Note that the percentage of first-year women enrolled in engineering in 1971 (2.6 percent) closely corresponds to the 1972 second-year (2.6), the 1973 third-year (2.7 percent), and the 1974 fourth-year enrollments (2.8 percent), as well as the B.S. degrees awarded in 1975 (2.3 percent). However, it does not provide insight into master's and

TABLE 2: Percentage Distribution of Probable Career Choices of College Freshmen, by Sex (Weighted National Norms), for Selected Years, 1978-1984

	1978		1979		1980		1981		1982		1983		1984	
FIELD	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Accountant/actuary	6.4	6.2	5.6	5.8	5.4	6.2	4.9	6.1	5.1	6.5	5.0	6.7	5.2	6.8
Actor/entertainer	0.8	1.0	0.9	1.1	0.9	1.0	0.8	1.0	0.7	1.0	0.8	0.9	0.7	0.9
Architect/urban planner	2.5	0.5	2.8	0.8	2.8	0.8	2.2	0.5	2.2	0.6	1.9	0.5	2.2	0.5
Artist	1.0	2.1	1.3	2.1	1.4	2.4	1.3	2.2	1.3	2.1	1.5	1.9	1.3	1.6
Business														
Clerical	0.3	4.6	0.4	4.1	0.3	3.9	0.3	3.8	0.3	3.5	0.3	3.6	0.4	3.5
Executive	11.3	7.3	11.6	8.2	11.1	9.2	11.2	9.4	10.8	10.1	11.3	10.0	12.5	11.4
Owner/proprietor	4.1	1.0	4.5	1.2	4.1	1.3	4.1	1.5	3.9	1.5	4.0	1.5	4.5	1.7
Salesperson/buyer	1.2	1.3	1.3	1.5	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.3	1.3	1.3
Clergy	0.8	0.2	0.7	0.1	0.7	0.1	0.7	0.1	0.5	0.1	0.5	0.1	0.4	0.1
Clinical psychologist	0.5	1.4	0.5	1.6	0.4	1.4	0.4	1.4	0.3	1.4	0.5	1.4	0.5	1.7
College teacher	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2
Computer programmer/ analyst	4.0	3.0	4.7	3.3	5.6	4.9	7.5	6.4	9.7	8.0	10.2	7.0	7.7	4.6
Conservationist/ forester	1.9	0.8	1.8	0.7	1.4	0.7	1.9	0.7	1.3	0.5	1.1	0.3	1.1	0.2
Dentist	1.4	0.6	1.2	0.6	1.2	0.7	0.9	0.5	0.9	0.5	0.9	0.6	0.7	0.5
Dietician	0.1	1.0	0.1	0.7	0.1	0.7	0.1	0.8	0.1	0.6	0.1	0.5	0.1	0.5
Engineer	16.5	2.2	16.8	2.3	19.1	2.9	19.5	2.9	20.6	3.6	18.8	3.3	18.5	2.9
Farmer/rancher	1.8	0.5	2.0	0.5	2.0	0.4	2.4	0.6	2.0	0.4	1.4	0.2	1.6	0.3
Foreign service worker	0.3	0.7	0.3	0.6	0.4	0.6	0.4	0.6	0.4	0.7	0.4	0.7	0.5	0.8
Homemaker (full-time)	0.0	0.3	0.0	0.4	0.1	0.2	0.0	0.3	0.0	0.2	0.0	0.1	0.0	0.1
Interior decorator	0.1	1.0	0.1	1.1	0.1	1.0	0.0	1.0	0.1	1.0	0.1	0.8	0.1	0.8
Interpreter	0.1	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.1	0.3	0.0	0.3	0.0	0.4
Lab technician/hygienist	0.7	3.0	0.6	2.7	0.6	2.3	0.4	1.9	0.5	2.0	0.7	1.9	0.4	1.5
Law enforcement officer	2.2	0.9	1.7	0.7	1.8	0.6	1.4	0.4	1.9	0.5	1.8	0.6	1.8	0.5
Lawyer/judge	5.3	3.4	5.0	3.4	4.8	3.5	4.5	3.4	4.7	3.9	4.2	3.6	4.4	3.7

Military career	1.8	0.4	1.9	0.3	1.7	0.2	1.8	0.2	1.6	0.2	2.0	0.3	2.1	0.3
Musician	1.6	1.2	1.6	1.1	1.5	0.9	1.5	1.0	1.4	0.9	1.2	0.9	1.2	0.7
Nurse	0.2	7.7	0.2	7.0	0.2	7.2	0.2	7.3	0.2	7.7	0.3	8.4	0.2	7.5
Optometrist	0.3	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
Pharmacist	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.5	0.3	0.5	0.5	0.7	0.5	0.8
Physician	4.3	2.8	4.0	2.9	4.1	2.9	4.0	2.9	4.1	3.1	4.5	3.4	4.5	3.5
School counselor	0.1	0.3	0.1	0.4	0.1	0.3	0.1	0.3	0.1	0.2	0.1	0.3	0.1	0.3
School principal/supt.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scientific researcher	2.7	1.7	2.4	1.3	2.2	1.3	2.0	1.2	1.8	1.2	1.8	1.2	1.9	1.2
Social/recreation worker	0.6	3.9	0.6	3.9	0.6	3.2	0.4	2.6	0.3	2.0	0.4	2.1	0.4	2.1
Statistician	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Therapist	0.5	3.4	0.6	3.5	0.6	3.4	0.6	3.6	0.5	3.3	0.7	3.8	0.9	3.8
Teacher (elementary)	0.4	6.8	0.5	7.0	0.5	6.9	0.4	6.4	0.4	5.5	0.3	5.7	0.4	6.1
Teacher (secondary)	2.0	3.0	2.1	3.0	1.9	2.4	1.6	2.4	1.4	1.9	1.8	2.1	1.8	2.5
Veterinarian	1.1	1.6	0.9	1.4	0.9	1.5	0.8	1.5	0.8	1.5	0.7	1.3	0.7	1.5
Writer/journalist	1.4	2.4	1.7	2.7	1.6	2.5	1.7	2.6	1.6	2.6	1.5	2.5	1.6	2.4
Skilled trades	3.1	0.4	2.7	0.4	3.2	0.5	3.1	0.4	2.9	0.3	2.7	0.4	2.4	0.2
Other	5.7	8.3	6.2	8.9	5.8	8.1	6.1	8.1	5.6	7.5	5.5	7.4	5.3	7.7
Undecided	9.6	11.6	9.4	11.4	8.9	11.3	8.8	11.3	8.1	10.8	8.8	11.3	9.2	12.3

SOURCE: American Council on Education, The American Freshman: National Norms, Los Angeles: Office of Research and Cooperative Institutional Research Program, University of California, 1978-1984.

TABLE 3: Percentage of B.S. Degrees Awarded to Women in Physical Science Areas

Year	Astronomy	Biochemistry	Chemistry	Geosciences	Physics
1971	7.8	24.3	18.7	11.4	6.8
1972	16.5	28.2	19.8	12.7	7.0
1973	20.9	22.4	19.2	12.7	7.3
1974	21.7	23.1	20.1	16.5	8.5
1975	17.4	26.5	22.4	17.4	9.7
1976	12.9	29.6	22.5	18.8	10.9
1977	15.6	29.2	22.8	21.6	10.5
1978	21.8	29.5	25.1	22.4	11.1
1979	21.5	32.9	26.7	23.5	12.0
1980	16.7	35.4	28.6	24.7	12.8
1981	16.4	35.7	29.9	25.1	12.6
1982	19.8	35.8	31.1	26.4	13.2
1983	26.7	38.2	34.1	25.8	12.7

SOURCES: National Center for Education Statistics, Earned Degrees Conferred series, Washington, D.C.: U.S. Office of Education, 1971-1983.

TABLE 4: Percentage of B.S. Degrees Awarded to Women in Computer Science, Mathematics, and Statistics

Year	Computer Science	Mathematics	Statistics
1971	14.6	38.2	25.3
1972	13.5	39.2	27.9
1973	14.9	40.3	34.8
1974	16.4	41.0	36.6
1975	18.9	42.1	31.9
1976	19.8	40.9	35.7
1977	23.9	41.5	43.4
1978	25.8	41.4	39.2
1979	28.1	41.7	38.3
1980	30.3	42.3	42.1
1981	32.5	42.8	47.0
1982	34.8	43.2	41.1
1983	36.3	45.7	48.7

SOURCE: See Table 3.

doctoral degrees awarded, due in part to the differential time values required to complete graduate degrees and the very large number of foreign national graduate students (for the most part, men) in engineering.

Table 7 (page 64) provides more up-to-date information, using 1985 enrollment and B.S. degrees awarded by discipline and data on some of the smaller, nontraditional, and newer fields of engineering. All of the engineering fields are significantly below parity. Most of the larger traditional fields continue to have the lowest percentage of women: aeronautical, agricultural, civil, electrical, marine, mechanical, nuclear, and petroleum engineering. The exceptions are chemical, ceramic, industrial, materials, and metallurgical engineering, where participation rates for women are significantly higher but still below parity. Some of the newer emerging areas--such as bioengineering, computer engineering, environmental engineering, and systems engineering--also have higher than average participation rates for women.

Biological Science. As can be seen from Table 8 (page 65), women are not currently underrepresented in most of the biological science and health-related fields. Some areas (nursing, medical technology, physical therapy, and speech pathology) have always been above parity at the undergraduate level. In other areas, including biological science and pharmacy, parity has now been reached. In the hospital and health administration field, there has been more than a tenfold increase in the percentage of B.S. degrees awarded to women (6.7 percent in 1970-71, 75 percent in 1982-83).

Social Science. The picture in social science (see Table 9, page 66) is mixed. The percentage of baccalaureates awarded to women not only increased in sociology, anthropology, and psychology, but significantly exceeded parity in 1983. However, the percentage of B.S. degrees awarded to women in economics, though still significantly below parity in 1982-83 (about 1 in 3 degrees awarded), was about triple the women's participation rate of 1970-71. The women's share of bachelor's degrees in political science almost doubled between 1970-71 and 1982-83.

Summary

In science and engineering, the proportions in which undergraduate women are represented vary considerably. In most of the biological and social sciences, parity has already been reached or exceeded: projections based on college major plans of freshmen indicate that women will continue to be at least equally represented. However, in the physical sciences and engineering, women continue to be underrepresented. Projections based on enrollments and intended majors of college-bound high school seniors and college freshmen indicate that the significant gains in participation rates made in the physical sciences and engineering during the 1970s have not continued in the 1980s, and there are some indications of regression.

TABLE 5: Bachelor's Awarded in Engineering, by Sex and Discipline,

Year	Aeronautical	Chemical	Civil	Electrical
1971-1975				
Total	8,745	17,510	36,959	58,528
Women	97	487	478	563
% Women	1.11	2.78	1.29	.96
1975-76				
Total	1,009	3,203	8,059	9,874
Women	29	276	252	193
% Women	2.87	8.61	3.12	1.95
1976-77				
Total	1,078	3,524	8,228	9,936
Women	28	420	429	266
% Women	2.59	11.91	5.21	2.67
1977-78				
Total	1,186	4,615	9,265	11,213
Women	61	716	690	435
% Women	5.14	15.52	7.45	3.88
1978-79				
Total	1,386	5,655	9,941	12,440
Women	66	1,006	955	659
% Women	4.83	17.79	9.67	5.30
1979-80				
Total	1,424	6,383	10,442	13,902
Women	82	1,215	991	902
% Women	5.76	19.03	9.49	6.49
1980-81				
Total	1,809	6,527	10,678	14,938
Women	129	1,252	1,121	1,096
% Women	7.13	19.18	10.50	7.34
1981-82				
Total	2,120	6,740	10,524	16,455
Women	171	1,467	1,191	1,409
% Women	8.07	21.77	11.32	8.56
1982-83				
Total	2,127	7,185	9,989	18,049
Women	172	1,616	1,321	1,774
% Women	8.09	22.49	13.22	9.83
1948-1983				
TOTAL	56,132	131,456	235,724	381,910
Women	1,044	9,050	7,846	7,944
% Women	1.86	6.68	3.33	2.08

*Includes engineering technology.

SOURCE: National Center for Education Statistics, <u>Earned Degrees Con-</u>

1971-1983

Industrial	Mechanical	Metallurgical	Mining	TOTAL*
15,935	40,734	2,687	1,115	220,704
194	295	48	10	2,971
1.22	.72	1.79	.90	1.35
2,241	6,841	351	331	38,774
87	147	23	8	1,317
3.88	2.14	6.55	2.41	3.40
2,240	7,703	350	404	40,936
143	235	21	9	2,022
6.38	3.05	6.00	2.22	4.93
2,712	8,924	420	509	47,222
323	466	44	22	3,479
11.91	5.22	10.48	4.32	7.37
2,804	10,171	503	600	53,445
428	603	81	35	4,880
15.26	5.93	16.10	5.83	9.13
3,217	11,863	585	682	69,265
545	882	100	51	6,438
16.94	7.43	17.09	7.48	9.29
3,833	13,329	603	750	75,000
756	1,136	116	61	7,699
19.72	8.52	19.24	8.13	10.27
3,992	13,922	592	662	92,989
943	1,220	98	48	9,981
23.62	8.76	16.55	7.25	10.73
3,748	15,675	645	597	89,199
987	1,443	117	44	10,951
26.33	9.21	18.14	7.37	13.28
77,642	325,326	16,297	8,398	1,535,088
4,555	6,874	707	292	52,974
5.87	2.11	4.34	3.48	3.45

ferred series, Washington, D.C.: U.S. Office of Education, 1948-1983.

TABLE 6: Percentage of Women Enrolled in Engineering, by Class, and Engineering Degrees Granted, by Degree Level, 1971-1985

	Enrollments by Class				Degrees Awarded		
Year	1st Year	2nd Year	3rd Year	4th Year	B.S.	M.S.	Ph.D.
1971	2.6	2.0	1.5	1.0	0.8	1.0	0.7
1972	3.0	2.6	2.1	1.5	1.2	1.8	0.9
1973	4.7	3.7	2.7	1.9	1.4	1.3	1.3
1974	6.7	5.4	4.0	2.8	1.8	2.5	1.1
1975	8.9	7.5	5.8	4.1	2.3	2.4	1.7
1976	10.4	9.3	7.8	5.6	3.6	3.4	1.9
1977	11.2	10.7	9.6	7.8	4.9	3.9	2.4
1978	12.3	11.7	10.7	9.3	7.1	5.0	1.9
1979	13.5	13.2	11.8	10.5	8.9	5.5	2.2
1980	14.5	14.2	12.8	11.8	9.7	6.3	3.2
1981	15.8	15.2	13.9	12.7	10.4	6.8	3.2
1982	16.6	16.4	15.0	13.8	12.2	8.4	4.4
1983	17.0	16.9	15.4	14.5	13.2	9.0	4.7
1984	16.5	17.0	15.5	14.8	14.0	10.1	4.7
1985	16.5	16.7	16.9	14.5	14.7	10.2	5.7

SOURCE: Engineering Manpower Commission, Enrollment and Degree reports, New York: American Association of Engineering Societies, 1971-1985.

TABLE 7: Percentage of Women Enrolled in Engineering Programs and B.S. Degrees Awarded to Women, 1985

Field	1st Year	4th Year	Total	Degrees
Aeronautical	11.81	8.28	10.26	8.2
Agricultural	7.89	11.97	10.65	9.5
Architectural	18.20	20.62	19.37	15.0
Bioengineering	38.34	32.78	34.39	28.7
Ceramic	26.37	26.73	27.53	23.3
Chemical	30.54	25.22	27.52	26.0
Civil	14.14	12.80	13.90	12.8
Computer	24.25	22.50	22.70	22.2
Electrical	12.60	12.32	12.76	10.8
Engineering science	16.48	16.74	17.64	18.0
Environmental	19.74	22.33	22.49	25.0
General	17.71	19.02	18.28	14.5
Industrial	30.24	27.86	30.34	28.2
Marine	11.80	9.40	9.57	6.3
Materials & Metallurgical	18.90	22.20	22.16	23.6
Mechanical	10.49	10.69	11.45	10.6
Mining	19.61	16.93	17.44	14.3
Nuclear	12.64	9.67	11.04	11.7
Other	45.00	22.67	38.91	27.3
Petroleum	14.60	11.16	12.16	11.7
Pre-engineering	17.47	18.51	17.88	—
Systems	24.14	28.59	27.30	37.6
TOTAL	16.50	14.50	16.00	14.7

SOURCE: See Table 6.

TABLE 8: Percentage of B.S. Degrees Awarded to Women in Biological Sciences

Year	Biological Science	Pharmacy	Nursing	Medical Technology	Hospital & Health Admin.	Physical Therapy	Speech Pathology
1970-71	29.4	20.7	97.9	87.6	6.7	80.0	87.7
1971-72	29.6	23.3	97.4	84.5	43.6	79.7	86.4
1972-73	30.0	25.1	97.0	81.5	13.2	78.6	87.8
1973-74	31.5	27.0	96.1	79.8	17.3	78.8	89.5
1974-75	33.3	28.1	95.4	78.7	32.4	76.1	89.6
1975-76	34.8	30.5	94.9	80.0	35.6	77.5	91.3
1976-77	36.2	32.5	94.6	80.2	47.9	76.7	92.0
1977-78	38.7	36.3	94.6	79.8	61.8	78.7	91.4
1978-79	40.6	39.9	94.3	79.1	64.6	78.4	92.8
1979-80	42.4	41.0	94.5	80.5	68.2	77.8	92.8
1980-81	44.1	43.8	95.0	81.9	66.0	80.6	93.6
1981-82	45.7	46.0	94.9	82.3	70.6	80.4	94.8
1982-83	46.1	49.0	95.3	81.0	75.0	80.4	94.6

SOURCE: National Center for Education Statistics, Earned Degrees Conferred series, Washington, D.C.: U.S. Office of Education, 1970-1983.

TABLE 9: Percentage of B.S. Degrees Awarded to Women in Social Sciences

Year	Sociology	Anthropology	Psychology	Economics	Political Science
1970-71	59.3	55.5	44.6	11.2	20.1
1971-72	57.0	54.4	46.4	11.8	18.8
1972-73	56.3	54.3	47.8	13.9	19.6
1973-74	57.3	55.5	50.5	14.7	20.4
1974-75	58.1	57.0	52.7	17.3	22.5
1975-76	59.3	57.4	54.3	19.6	25.3
1976-77	60.8	58.6	56.6	22.9	28.8
1977-78	63.4	60.2	58.9	25.0	31.1
1978-79	65.2	61.3	61.3	27.5	33.4
1979-80	66.7	62.6	63.3	30.2	35.9
1980-81	69.6	63.3	65.0	30.5	36.8
1981-82	70.3	63.4	66.8	32.5	38.1
1982-83	69.7	64.7	67.5	33.3	39.3

SOURCE: National Center for Education Statistics, Earned Degrees Conferred series, Washington, D.C.: U.S. Office of Education, 1970-1983.

Factors Influencing Initial Enrollments

The underrepresentation of women in selected engineering and science fields has been central to a large number of studies, most of which have focused on identifying factors associated with gender differences by using aggregate data, surveys, and correlational studies. Very few experimental or quasi-experimental studies have been conducted. Nevertheless, important sources of information and data emerging from these studies provide a basis for understanding not only the factors related to the underrepresentation of women in science and engineering, but also methods to remedy that situation.

Although there is little overt evidence of discrimination against women in the college admission process, the abundant covert explanations and rationalizations regarding the lower representation of women in engineering and the physical sciences usually focus on two major cognitive areas: (1) college-bound women do not have adequate preparation in mathematics and physical science to pursue the rigorous demands of beginning engineering and quantitatively-oriented science programs, and (2) college-bound women score lower than men on college admissions examinations. To the extent that mathematics and physical science preparation or college admission test scores are used in the college admissions process, these sometimes subtle requirements do significantly reduce the pool of women eligible for admission to institutions and programs that focus on engineering and science.

Mathematics and Physical Science Backgrounds

NSF (1986b) has compiled data supporting the stronger mathematics and physical science backgrounds of high school senior and college freshman males compared to females. In addition, Surveys of High School and Beyond, 1980 (U.S. Department of Education, 1982) provide illustrative data. In 1980, high school senior boys were more likely than girls to have taken courses in trigonometry (30 versus 22 percent), calculus (10 versus 6 percent), chemistry (39 versus 35 percent), and physics (26 versus 14 percent). Table 10, which provides similar data for those graduating in 1982, indicates that high school females continue to be less likely to attempt advanced math and physical science courses.

Table 11 (pages 70-71) documents the changes that have taken place between 1971 and 1985 in the reported mathematics and physical science preparation of college-bound male and female seniors who took the College Entrance Examination Board exams. In the early 1970s, only about one-third of the college-bound women had at least four years of high school math and two years of physical science, compared to over one-half of the college-bound males. The 1985 data on college-bound students indicate a much smaller gender gap: approximately 60 percent of the college-bound women take four or more years of math and two or more years of physical science, compared to about three-fourths of the college-bound men. It should be noted that college-bound women and men reported virtually the same grades in math and physical science, both in 1971 and in 1985.

College Board Scores

Unfortunately, these changes in math and science preparation have not affected college admission test scores, which have declined in the past two decades. As shown in Table 12 (page 72), college-bound women have lower scores than men on both the SAT-Verbal and the SAT-Math. Women had slightly higher SAT-Verbal scores than men in 1970 (461 versus 459) and in 1971 (457 versus 454), but slightly lower scores since 1972. Mean scores on the SAT-Math for college-bound women have been consistently lower than for men; 466 versus 507 in 1971, 445 versus 497 in 1977, and 452 versus 499 in 1985.

There are differences in opinion, indeed controversy, regarding the factors accounting for the mathematical test gender differentials. The social-psychological explanation attempts to attribute the differences to family socialization practices as well as temperament, interest, and attitudes, or to biological and experimental factors (Maccoby, 1966). However, a more generally accepted sex-role socialization analysis points to the inhibition of women to perform at high levels of accomplishment, especially in quantitative-analytical areas, ranging in source from "fear of success" stereotypes to "no women allowed or encouraged" discriminatory practices. The result is that women avoid courses and experiences at school and at home that would enhance their mathematical and science backgrounds and competencies--the differential coursework hypothesis.

TABLE 10: Types of Mathematics and Science Courses Attempted by 1980 High School Sophomores Who Graduated in 1982, by Sex (in percent)

Sex/Racial/ Ethnic Group	Mathematics					
	Algebra I	Geometry	Algebra II	Trigonometry	Analysis	Calculus
TOTAL	67.7	54.2	34.3	22.9	8.9	6.9
Male	66.1	53.9	35.2	25.8	9.9	8.2
Female	69.3	54.4	33.5	20.0	7.8	5.7

	Science						
	Physical Science	Advanced Biology	Biology	Chemistry	Chemistry II	Physics	Physics II
TOTAL	67.8	78.8	18.0	35.5	4.4	16.9	1.7
Male	70.5	77.0	16.4	36.4	5.2	22.1	2.6
Female	65.1	80.7	19.6	34.5	3.6	11.6	0.9

SOURCE: National Science Foundation, Women and Minorities in Science and Engineering (NSF 86-10), Washington, D.C.: U.S. Government Printing Office, 1986, p. 152.

More recently the differential coursework hypothesis was challenged in a controversial research project on gifted math students by Benbow and Stanley (1980). These researchers indicated that the gender differences in SAT-Math scores are not due to differences in math preparation alone, but to differences in the mathematical reasoning abilities of boys and girls. Their results were challenged by Luchins and Luchins (1981), Stage and Karplus (1981), and Tomizuka and Tobias (1981) and counter-challenged by Benbow and Stanley (1981). A more pragmatic research resolution to the problem was presented by Pallas and Alexander (1983) based on analysis of a representative group of 6,000 students who took both the SAT-Math as twelfth-graders and the SCAT-Math in the ninth grade. Their study indicates that females score somewhat lower than males on the SAT-Math, largely because they are less likely to enroll in quantitatively-oriented courses (geometry, trigonometry, calculus, and physics). However, higher grades in math courses of women than of men were a positive factor. Other factors--socioeconomic status, race, and gender--had small but statistically significant influences on SAT-Math scores. They conclude:

> We find that the male-female gap in SAT-M performance shrinks considerably when sex differences in quantitative high school course-work are controlled. These findings suggest that increasing females' rates of enrollment in high level mathematics courses would greatly reduce the sex difference in quantitative SAT performance and that it is premature to reject socialization and experimental explanations for the male-female gap in levels of quantitative performance. . . .
>
> Although the present research, and that of others, indicates that sex differences in mathematics performance arise during the high school years, we believe it is quite likely that many of the mechanisms responsible for the male-female gap in performance are set into motion much earlier, perhaps even in the elementary grades. (Pallas and Alexander, 1983: 165, 180)

The general consensus is that these gender differences in college admission math test scores can be largely accounted for by the differences in the amount of mathematics, physical science, and computer programming courses that high school and college-bound women take compared to their male peers. Also, some evidence suggests that prior to and during college, women--including those who major in engineering and science programs--are less likely to engage in extracurricular and personal activities that might enhance either quantitative or physical science achievement (e.g., computer camps and science fairs) or mechanical and problem-oriented activities (e.g., reading Popular Mechanics, doing construction, and acquiring electronic hobbies).

TABLE 11: College-Bound Students' High School Preparation and Grades

	Preparation in Years						
	None	1	2	3	4	5+	Mean
1971							
Mathematics							
Men	0	2	11	29	50	9	3.50
Women	0	4	14	40	33	4	3.10
Physical sciences							
Men	13	31	37	17	2	0	1.60
Women	24	45	25	5	0	0	1.10
1975							
Mathematics							
Men	0	2	10	27	51	10	3.57
Women	0	3	20	37	35	5	3.17
Physical sciences							
Men	9	34	34	17	5	1	1.80
Women	15	43	29	9	4	0	1.45
1981							
Mathematics							
Men	*	2	8	23	54	13	3.68
Women	*	2	15	32	43	8	3.38
Physical sciences							
Men	6	26	36	24	5	2	2.01
Women	11	38	34	14	2	1	1.59
1984							
Mathematics							
Men	*	1	7	20	56	16	3.78
Women	*	2	11	28	49	10	3.34
Physical sciences							
Men	6	25	37	25	6	2	2.05
Women	9	37	36	16	3	1	1.69
1985							
Mathematics							
Men	*	1	6	20	58	15	3.80
Women	*	1	10	28	51	10	3.58
Physical sciences							
Men	5	24	38	27	6	2	2.08
Women	8	34	38	17	3	1	1.74

*Less than 1 percent, but not zero.

SOURCE: Educational Testing Service, National College-Bound Seniors, 1985.

in Mathematics and Physical Science, by Sex, 1971-1985 (in percent)

	Grade in Course						
	A	B	C	D	F	Pass	Mean
1971							
Mathematics							
Men	26	35	28	9	2	0	2.70
Women	26	36	28	8	2	0	2.80
Physical Sciences							
Men	27	39	27	5	0	2	2.40
Women	26	39	26	5	0	3	2.40
1975							
Mathematics							
Men	28	38	26	6	1	0	2.87
Women	27	34	27	7	1	0	2.84
Physical Sciences							
Men	33	43	21	3	0	0	3.05
Women	30	45	21	3	0	1	3.02
1981							
Mathematics							
Men	27	39	27	6	1	*	2.85
Women	26	39	28	6	1	*	2.83
Physical Sciences							
Men	29	42	25	4	1	*	2.94
Women	28	48	25	4	1	*	2.94
1984							
Mathematics							
Men	27	39	27	6	*	*	2.86
Women	26	39	28	6	1	*	2.84
Physical Sciences							
Men	28	41	25	4	1	*	2.92
Women	27	43	25	4	1	*	2.92
1985							
Mathematics							
Men	27	39	27	6	1	*	2.85
Women	26	39	27	6	1	*	2.87
Physical Sciences							
Men	28	41	26	4	1	*	2.91
Women	27	43	26	4	1	*	2.91

Princeton, N.J.: Admissions Testing Program, The College Board, 1971-

TABLE 12: SAT Score Averages for College-Bound Seniors, by Sex, 1970-1985

	Verbal		Mathematics	
Year	Male	Female	Male	Female
1970	459	461	509	465
1971	454	457	507	466
1972	454	452	505	461
1973	446	443	502	460
1974	447	442	501	459
1975	437	431	495	449
1976	433	430	497	446
1977	431	427	497	445
1978	433	425	494	444
1979	431	423	493	443
1980	428	420	491	443
1981	430	418	492	443
1982	431	421	493	443
1983	430	420	493	445
1984	433	420	495	449
1985	437	425	499	452

SOURCE: Educational Testing Service, National College-Bound Seniors, Princeton, N.J.: Admissions Testing Program, The College Board, 1970-1985.

Women and Computers

An analysis of factors having an impact on enrollment of women in engineering and science fields cannot ignore the increasing differences in the precollege computer backgrounds of male and female students. Armstrong (1986) reviewed the current literature and found gender differences in computer access, usage, and interest:

> In order to develop a background in computer programming, students need access to computers. Gender differences in computer access and usage have been of critical interest during the past five years. A California state-wide assessment of computer literacy at the sixth and twelfth grades concluded that girls either have or take fewer opportunities to work on computers at both home and school than do boys. More often than girls, twelfth-grade boys are inclined to learn about computers at home from friends or through the use of video games. More sixth-grade boys than girls are likely to have home computers. Even though both male and female students reported learning about computers at school, females exhibited a pattern of less participation and access than

that of males (Fetler, 1985). Boss (1982) reported that girls did not have the same amount of time on computers in schools because they did not take the time to use the machines. These findings concur with Sheingold, et al., (1983), whose research indicated that gender differences in computer use spanned all grade levels, with males having higher amounts of usage and access. At the secondary level, computers were polarized in the mathematics/science and business areas, where women students tended to use only the machines in the business area (Sheingold, et al., 1983).

Several studies investigated gender differences in computer camp registration. Three times more males than females registered in computer camps with differences more pronounced at the secondary level than at the elementary level (Hess and Miura, 1985).

Gender differences in computer access and usage were found in the homes of students as well. Fathers tended to bring the computer into the home and teach others how to use the machine. In addition, families were more likely to buy a computer and spend more money on computer software and peripherals for male children than for female children (Miura and Hess, 1984).

At the precollege level, more male students than female students indicated interest in computer programming courses (Becker, 1982; Hess and Miura, 1985; Fetler, 1985). The gender differences widen at the more advanced levels of education (Lepper, 1985). In computer camps, merely five percent of the girls took the assembler language courses (Hess and Miura, 1985). Lepper reported similar discrepancies in participation in the advanced courses in programming. Linn (1985) reported that women constituted 86 percent of the students in word processing, but only 37 percent of those in computer programming.

Results of a Computer Literacy Scale administered to beginning engineering freshmen at Purdue University in 1985 and replicated in 1986 indicated that significantly more males than females had written and debugged programs, listed a program, saved a program, renamed a program, used a program to solve a mathematics problem, modified someone else's program, instructed others in the use of a computer, documented a program, used a word processor, and used a computer at home. The only item on the scale that did not indicate significant gender differences was "used a computer at school" (Armstrong, 1986; Armstrong, et al., 1985; Armstrong, et al., 1986). Furthermore, the male engineering students entering college had completed more weeks of high school instruction in computer programming and knew more computer languages than their female counterparts (Armstrong, et al., 1986).

Several researchers have attributed the gender differences in computer background to differences in interests and attitudes. Armstrong (1986:26-27), in her survey of the literature, reported the following:

A number of studies have found that men indicate more interest in computers than do women (Lockheed, Nielsen, and Stone, 1983; Hess and Miura, 1985; Campbell and McCabe, 1984; Fetler, 1985). Differences in interest in computer programming have also been documented (Becker, 1982). However, once men and women were enrolled in the same computer programming course, their levels of interest tended to be similar (Schubert, 1984). Research has not been conducted that is designed to identify whether interest extends beyond the duration of the course. In addition, differences in interest in computers do not extend equally over all grade levels. More significant gender differences in interests in computers at the sixth-grade level were found than at the twelfth-grade level (Fetler, 1985).

Self-efficacy (self-appraisal of one's ability to successfully complete a task) has been proposed by Bandura (1982) as a factor that may determine whether a person will engage in a task. In the computer field, Miura and Miura (1984) reported that male students had significantly higher perceived self-efficacy for computer-related tasks. These differences in self-efficacy were also reported among junior high school adolescents (Miura, 1984). Women engineering students, in general, reported lower self-perceived abilities than did male students (Linden, et al., 1985). Self-perceived abilities could help to explain gender differences in enrollment in computer programming courses.

Researchers have proposed a myriad of reasons for the observed gender differences concerning interests and attitudes towards computers. The reasons include sex stereotyping, which begins in the second grade (Stein and Smithells, 1969), traditional differences in mathematics and science (Winkle and Mathews, 1982; Lockhard, 1980), the placement of the computer in the mathematics and science departments (Saunders, 1979), sex differences in spatial abilities (Aiken, 1972), public stereotyping of the computer as a man's machine (Hawkins, 1985), and the male-orientation of the major proportion of available software (Miura and Hess, 1984). All of these reasons, and many more, can help to explain the documented differences in interests and attitudes.

If male students tend to possess higher levels of computer background and interest, do they out-perform female students in computer programming courses? In general, research findings indicate that there is no difference between the academic performance of male and female students in computer programming courses, even though computer background differences may be present at the beginning of the course (Armstrong, 1986; Armstrong, et al., 1986; Campbell and McCabe, 1984; Mandinach and Fisher, 1985). One contrary finding in a study concerned with teaching LOGO programming to elementary school children was that boys exhibited higher levels of academic achievement than did girls (Pea, et al., 1984).

To summarize, there seems to be evidence, at least in the precollege years, that males have higher levels of interest in, access to, and participation in computer-related activities including games, computer camps, and computer programming courses than females. In general, there are no gender differences in academic performance in computer programming courses at the precollege or college level. Linn and Dalbey (1985:202) summarized their "quasi-experimental" study of various computer-intensive sites by stating that gender differences, not evident in performance, were shown in interest in enrolling in computer courses: "The point where equity seems most central is in securing the participation of females in programming courses."

Comprehensive Studies Related to Undergraduate Participation of Women in Science and Engineering

A number of studies that provide comprehensive views of the factors influencing the underrepresentation of women in science and engineering have special relevance at the undergraduate level. Five major ones cited below are as follows: Engineering Education and Practice in the United States (National Research Council), An International Perspective Regarding Women in Engineering (Australian Bureau of Labor Market Research), Impact Analysis of Sponsored Programs To Increase the Participation of Women in Careers in Science and Technology (Denver Research Institute), Women in Engineering [National Center for Higher Education Management Systems (NCHEMS)], and Women in Engineering (Georgia Institute of Technology). In addition, information is provided about still other studies of women's participation in science and engineering in other sections of this report.

Engineering Education and Practice in the United States (National Research Council)

In 1980, NSF asked the National Research Council to conduct a study of the state and future of engineering education and practice in the United States. During the next five years, a committee of the Council's Commission on Engineering and Technical Systems conducted comprehensive studies and analyses. Of special relevance to women in engineering and science were the final report and the panel reports on undergraduate engineering education, graduate education and research, and infrastructure diagramming and modeling (National Research Council, 1985a, b, c). The latter report documents the tenfold increase in freshman enrollments and the seventeenfold increase in B.S. degrees awarded to women, indicating that the rapid increase in numbers of B.S. degrees in engineering came from two major sources, incoming freshmen and transfers from other fields and institutions.

The undergraduate panel's central observation was that two factors central to the supply of women are institutional differences and field differences (National Research Council, 1985a:24):

In 1982 the percentage of B.S. degrees awarded to women

> from the 50 institutions having the largest number of undergraduate engineering students ranged from a high of 29.5 percent (General Motors Institute) to a low of 8.9 percent (Iowa State University). The largest number of B.S. degrees awarded by one school to women in 1982 was 203 (15.6 percent) from Texas A&M University, which graduated the largest total engineering class that year. The numbers also vary across engineering fields: in 1982, 29 percent of industrial engineering students (the highest percentage) and 24.5 percent of computer engineering students were women, while 10 percent of mechanical engineering students (the lowest percentage) and 13 percent of civil engineering students were women.

The report also calls attention to two major curricular factors related to the preparation of women for engineering:

> The percentage of women in engineering programs appears to have no inherent limit. There are as many young women as men in high school who study mathematics and science through trigonometry and chemistry. However, almost twice as many young men as women take high school physics, calculus, and introductory computing.

Other observations of relevance in the undergraduate panel report include the following:

> Apparently an interest in physics is an important factor leading to a career in engineering; men are attracted to engineering mainly by taking high school physics, while women are attracted to engineering through chemistry and biology. High school women often feel tracked away from physics; very few physics teachers are women, and course content and quality are quite variable, often not appealing to women. Educational experiments indicate that nontraditional approaches to the teaching of both physics and introductory computer subjects in sex-balanced classes result in their increased appeal to women students.
>
> The increased number of women students has helped make engineering schools a more attractive environment for them. Despite recent improvements, however, women students will report feelings of isolation, lack of acceptance by faculty and male student peers, and lack of acceptance of their career goals by friends, family, and their universities. Many women students still find engineering schools to be stressful environments, and they need support to help them deal with the difficulties that they encounter. But they do not form a homogeneous group, and their needs vary. For example, some report significant problems in adjusting to a strongly male environment; some find a supportive environment in a particular department; and many find support in a confidant, sometimes a close male friend. Some of these are problems

> that will lessen over time as the number of both women students and women faculty increases.
>
> While increased use of foreign nationals as graduate teaching assistants and as faculty members is often cited as a problem because of language barriers, the practice also brings special problems for women students. Anecdotal evidence suggests that students and faculty from cultures in which the role of women is subservient may not be sensitive or sympathetic to the career aspirations of American women engineering students. . . .
>
> The Panel on Undergraduate Engineering Education recommends that, to achieve the full potential that this human resource offers, colleges of engineering, school systems, government, industry, and the engineering profession continue to work to increase the number of qualified women who study for a career in engineering. A key requirement is the need to encourage the study of mathematics and science by female secondary school students. (pp. 24, 26)

This final report in the Research Council's comprehensive engineering study includes especially relevant observations (1985a:6-8):

> Since the early 1970s, considerable effort has been devoted to increasing the participation of women and minorities in engineering. The recruitment efforts have paid off: the percentage of minorities in the engineering work force has doubled and the percentage of women has more than tripled. Currently, more than 15 percent of engineering undergraduate students are women (as compared to about 1 percent in 1970), which has generated a feeling of success among many of those concerned with the issue.
>
> However, some sobering facts should be pointed out. Compared with the sciences and other professional disciplines, women are still a small part of the engineering work force. Perhaps even more significant, beginning in 1982 there has been a mild slowdown in enrollments of women in engineering. . . .
>
> The committee believes that the determination of appropriate levels of representation in engineering for both women and minorities is not a matter for judgment by panels of educators and industry representatives. These are social questions requiring broader discussion. However, both women and minorities are represented as students and as practitioners in engineering at lower levels than in other science and technology professions. Therefore, the committee concludes that the participation of women and minorities in engineering should be matters of continuing concern to the engineering community. There is still much to be done.
>
> A case in point is the treatment of women on engineering faculties. There is a recurring perception of bias against female faculty members in assignment of teaching responsi-

bilities, in selection for research teams, and in granting tenure. In many schools there also appears to some to be a bias against female graduate students as candidates for faculty positions and in the provision of financial and intellectual support. College administrators should make a candid assessment of the attractiveness of academic life for women in their institutions, and if negative aspects such as these are found, they should take firm steps to eliminate them.

An International Perspective Regarding Women in Engineering (Australian Bureau of Labor Market Research)

In spite of limited time and resources, Byrne (1985), in a study for the Australian Bureau of Labor Market Research, was able to collect, analyze, and synthesize considerable data on women in engineering from a wide variety of international sources. A number of her conclusions and recommendations have special meaning and significance internationally:

> The male-dominated leadership of the engineering profession, unlike most people, is now coming to recognize that technology is androgynous. . . .
>
> The first matter to be stressed is that, while the research and studies reviewed in this report provide a firm base for strengthened hypotheses and for choosing some policy options, they do not yet provide decisive or conclusive evidence on the causes of female under-recruitment or success in engineering. Few have looked at longitudinal effects or trends. Secondly, most studies are either macro and statistical where not enough is known about the cohort's personal characteristics, or micro in detail and not always wholly transferable.
>
> Nor is enough known about actual sex differences in science and technology students. What is clear is that sex differences between successful male and female students--those who enroll--are often minor. But it is not clear what the key differences are for those who do <u>not</u> enroll. . . .
>
> Many questions are still unanswered and require further research. Research has not yet produced adequate answers about why women choose some branches more readily than others. . . .
>
> The importance issue for further enquiry are those of institutional and discipline variations, two factors which are common in all countries reviewed (whatever their educational structures). Further research is needed to explore these.
>
> Respondents were asked about the profile of women engineers. Some of the data collected are encouraging--their equal ability, high achievement, short or non-existent child-rearing gap and so on. Again, however, the data do not exist

in readily available form to support firm predictors yet of "successful" and "unsuccessful" profiles.

In summary, Byrne noted the significant growth in the number of women engineers since 1974. Positively influencing the growth were "institutional commitment, increased 'carrots' or 'sticks' by way of grants or special interest group pressure, manpower and womanpower shortages, and new fields opening up (computing and biomedical) which are less male-oriented from the start." In addition, she cited the following negative influences:

- Refusal to accept responsibility for the problem, or acceptance only if (a) women do not compete with men for rationed places and become a threat and (b) institutions do not have to reallocate existing resources;
- Refusal to accept that "the best man for the job may be a woman";
- Lack of leadership from the professional institutions;
- Adverse public image of engineering;
- Lack of resources from institutions, government grants, or industry to fund new programs;
- Lack of role models or use of them;
- Need to educate parents and teachers and bring them into the twentieth century in terms of changing sex roles;
- Male-oriented, biased, out-of-date or non-existent career advice, usually also too late to influence or save curricular choices;
- Career influence in senior high school is too late (intervention should start in junior high school); and
- Deficiencies in math and physics.

An Impact Analysis of Sponsored Programs To Increase the Participation of Women in Careers in Science and Technology (Denver Research Institute)

Another related study was conducted by the Denver Research Institute in order to evaluate and to assess six experimental programs related to those projects: those at the University of Kansas, Queensborough College, the University of Missouri at Kansas City (UMKC), Rosemont College, and Massachusetts Institute of Technology and a program originally developed under an Institute for Educational Development grant and completed by the Policy Studies in Education group in New York.

A number of conclusions and recommendations emerged from that report including the following (Lantz, et al., 1976:1-2):

> The first recommendation is that given the emphasis on professional careers in science, concentration on high ability women is a realistic restriction. Second, the more able and/or more mature women appear to be more interested in content of the vocation, while younger or less able women are

more interested in lifestyle possibilities relevant to any career. A trade-off between age and ability was noted; and increase in ability level may decrease the appropriate age. The third recommendation was that the programs concentrate on women who have already shown an interest in science and have the prerequisite background after the junior year in high school. It was also recommended that a distinction between career education and programs to interest women in science-related careers be made. The general conclusion was that recruitment and commitment should be emphasized in high school years; reinforcement, support and retention be emphasized in the college years; and that removing institutional barriers should be emphasized in graduate school, reentry programs for mature women, and post-employment programs. It was concluded that most of the participants felt strongly that all-female workshops and classes were necessary under certain conditions.

Another general conclusion was that role models appeared to be the most effective component of most of the projects. It was recommended that a mixture of role models, closer in age and accomplishment level to the participants, be utilized in conjunction with inspirational models, successful women at the top of their fields. It was also suggested that reentry programs might be more successful in recruiting underemployed, rather than unemployed, women. Another recommendation was that the National Science Foundation develop a strategy to disseminate the curriculum materials of each of the projects. It was also suggested that the Foundation take the responsibility for making evaluation instruments of established reliability and validity available to the project directors and for providing technical assistance in their internal evaluation efforts. A conference of all federal agencies involved in career education was also recommended to provide a means to pool available resources, and to avoid duplication of effort. Finally, it was recommended that the Foundation continue its activities in encouraging women to choose science as a career and to disseminate knowledge about the existence of its programs.

The fourth chapter in the report discussed alternative interventions. It began with a list of psychological, sociological, and institutional barriers to the participation of women in science-related careers. Some assumptions were delineated, and different kinds of interventions or treatments were proposed. Each of the possible interventions was categorized by educational level (e.g., elementary school, high school, college, graduate school, reentry, and postemployment programs).

Lantz and her colleagues stated four major assumptions and provided specific interventions for each. As possible interventions to the assumption that "knowledge that science-related careers are open to women is a prerequisite for pursuing those careers," the following were suggested:

- Workshops and seminars portraying professional women in science careers. Several NSF-sponsored projects are implementing this approach; for example, Mary Baldwin College was funded for seminars in 1975, and many more have been funded in 1976. These workshops might encompass three components of discussion by or with the role models: actual job content, lifestyles, and on-the-job problems. Depending upon the interests of the participants, the various aspects could be differentially emphasized. For many science majors, the different job titles that may be pursued from a science major may be of the most interest. For other groups, life-style preparation and solutions of on-the-job problems (if any) may be of more interest.
- Increase in the number of female science professors. Even though the majority of women having careers in science specialize in teaching, the percentage of full professors is very low in the sciences. The most obvious and most available role model for women interested in science would be their professors. In addition, it is likely that female professors may be more supportive of female undergraduate majors than male professors. Therefore, programs to increase the number and status of female professors are encouraged. The programs to increase the number may encompass all of the programs suggested in this section, and there may be many years before results are observed. Direct support of programs to increase the status of current female professors may produce results in a shorter time period. Many such programs are referenced in the section on programs for women currently in the labor force. (p. 69)

A second assumption was that "career-committed females may benefit from special counseling, support group activities, and other forms of social encouragement" (Lantz, et al., p. 69). Two possible interventions were given:

- Special counseling or support groups for women planning to pursue nontraditional science careers. These special counseling or support groups may take many forms. The groups might be task-oriented around special courses that would interest primarily females or be more social in nature. Whatever the vehicle used, the major aim would be to decrease the alienation and social pressure by encouraging friendships among women with similar values and aspirations.
- Special housing for women planning to pursue nontraditional science careers. While special housing presents many difficulties at large universities, group housing has been shown to increase the retention rate of female engineering majors. Wherever this may be an option, different housing arrangements may be tried. (pp. 69-70)

In addition, Lantz, et al. (1976:70) noted that "many fail to pursue science-related careers because they fail to successfully complete prerequisite mathematics courses." They suggested that remedial mathematics courses, innovative teaching methods, and special tutorial programs might encourage interest in scientific careers:

> Offering "remedial" mathematics courses or special courses, such as the UMKC project, may be an appropriate vehicle to assist women who are interested in science but have difficulty in advanced courses because of inadequate backgrounds in math. Even for those women successfully completing mathematics at the high school level, innovative approaches to teaching mathematics could be applied to advanced courses, such as solid geometry and calculus. For women taking advanced mathematics courses in college, special tutorial programs, run by other women, might assist their colleagues. The women interviewed at the University of Kansas expressed their shyness with male tutors and reluctance to ask the teachers for help. They felt that not understanding a single lesson usually meant it was impossible to comprehend any subsequent lesson. Therefore, they wanted female tutors who were immediately available and consistent.

Finally, this study noted that because "tangible and intangible institutional barriers discourage women from pursuing science-related careers" (p. 70), colleges and universities should take specific steps to alter the situation:

- Increasing the number and percentage of women holding undergraduate assistantships in teaching and research in the sciences. A "spin-off" of at least one of the experimental projects (not currently complete) seems to be the very positive effects of hiring junior and senior science majors as staff personnel. It not only served as a financial aid, but also it was interpreted as a "vote of confidence" and served to increase interest, exposure, and expertise in their areas. Assistantships also provide additional encouragement to go to graduate school and usually provide a closer relationship with a faculty member. Assistantships to declared science majors may improve the retention rate and result in more women attending graduate school in science.
- Increasing the number and percentage of women in science-related cooperative and intern programs, as is now attempted by one of the current NSF-sponsored projects. Such programs should result in a better understanding of job options, job requirements and preferable job alternatives (discovering that one doesn't like a job is as important as discovering that one does). Further, it may provide better "connections" to obtain a job or to gain admission to graduate school.

- Rewriting graduate "fellowship" brochures. One discouraging factor in applying for graduate school is the way information on financial aid is presented. The brochures, especially on the most prestigious "fellowships," are uniformly written in masculine gender and appear to rule out women.
- Increasing the number and percentage of female science professors (advisers). (pp. 70-71)

Women in Engineering: An Exploratory Study of Enrollment Factors in the Seventies (National Center for Higher Education Management Systems)

A special study under a National Institute of Education contract (Corbett, et al., 1980) examined general trends in enrollment, attrition, and degrees granted as well as case studies of six institutions (Vanderbilt, University of Washington, Purdue, Colorado School of Mines, Prairie View, and New Mexico State). It concluded that external causes and conditions were the primary factors that influenced the increased participation of women in engineering education and that internal influences were primarily facilitative.

External factors that seemed to lead to the increased enrollment of women in engineering programs during the past decade include the following:

- Job market outlook for engineers generally and opportunities and competitive salaries for women in particular,
- Industry recruitment of women for engineering positions and industry support of engineering-education programs through funding of scholarships, co-op programs, summer employment, and campus career institutes for prospective students,
- A change in the image of engineering as a field now central to public-policy and environmental issues,
- A change in society's attitude toward women's roles in the work force and the consequent change of women's attitudes and awareness regarding engineering as a career,
- Federal financial-aid programs for students,
- Affirmative-action pressure on industry,
- High school teachers and counselors encouraging students to acquire academic backgrounds and interests relevant to engineering studies, and
- Parental and family influence on the role perceptions of women students and their choices of college or university.

The NCHEMS study stressed that these external forces do not operate in isolation, but instead interact synergetically to create both constraints and opportunities. Similarly, engineering schools and their universities "are lodged in a complex network of formal organizations that influence each other" (p. 121), including both the businesses and industries hiring their graduates and high schools from which the engineering students traditionally come.

Internal factors were also cited by Corbett, et al. (1980:121-123), as influencing increased women's enrollment in engineering programs:

- Enrollment declines, which create a new awareness of women as a potential new pool of students,
- Recruitment efforts to make high school women aware of opportunities for them in engineering,
- Persistent efforts to increase the number of women in engineering programs,
- Support from both administrators and faculty,
- Designating responsibility for coordinating efforts to attract and support women in engineering programs,
- Student organizations that provide social support and professional affiliations for women students in engineering,
- Scholarships for incoming and returning women students in engineering,
- Retention activities directed to the particular needs of women students, and
- Location of the institution.

While many of these efforts were not specifically intended to help women, prevailing societal forces made larger numbers of women more likely to take advantage of them because (1) they were high achievers in high school, and (2) they came from families and socioeconomic backgrounds such that a choice of an engineering major was a relatively minor shift from a choice of science or math in college, which they might otherwise have made. Corbett and his colleagues noted, "The particular coincidence of the efforts of engineering schools to recruit more students and the readiness of more women to entertain nontraditional careers probably explains why many schools felt that the increase in the numbers of women appeared to 'just happen,' without extraordinary effort on their part" (p. 123).

Other, more subtle, influences were also identified in the NCHEMS study as factors influencing the increasing representation of women in science and engineering:

- Available information about students (grade-point average), prospective students (SAT and ACT scores), and programs (retention rates),
- Federal initiatives, such as direct financial aid to students, funding for research and demonstration projects that have given an impetus to women's enrollments in engineering (for example, the NSF and HEW grants to New Mexico State University and the Women's Education Equity Program Grant to Purdue University), legislation that legitimizes support for affirmative action and puts pressure on industry to respond, contracts with industry to develop or produce goods and services that keep the job market for engineers favorable, and compilation of data that indicate the relative positions of women in engineering and the sciences, and

- Activities of professional associations, such as support to student engineering organizations, national meetings and workshops, publications that express concerns about women in engineering, and information exchange networks and clearinghouses (such as the Women's Educational Equity Act Program Network) for research on and exemplary practices concerning women in the professions.

The authors also noted that increasing the enrollments of women in engineering programs has required no changes in curriculum, basic admission policies, or quality standards. They concluded,

> Indeed, the expansion of the applicant pool by attracting more competitive women has apparently helped maintain high overall admissions standards during periods of decreased enrollments. The main enterprise of engineering education has not been changed, either to stimulate or to accommodate women students. Faculty resistance has not been an issue, presumably because little or no change was required of most faculty. The large majority of the women entering engineering programs have been good students, and programs for recruiting and supporting them rarely threatened existing resources.
>
> The composite picture formed by these case studies shows the institution reacting without resistance to a confluence of environmental forces conducive to the increased enrollment of women in nontraditional programs. . . . (pp. 125, 126)

In other words, as the numbers of women increase, some of the barriers to women implicit in an environment where they are a small minority are lowered without conscious institutional effort (Kanter, 1977).

Women in Engineering: Policy Recommendations for Recruitment and Retention in Undergraduate Programs (Georgia Institute of Technology)

This study, conducted under a grant from the Fund for the Improvement of Postsecondary Education, focused primarily on recruitment, although some attention was also given to retention. Thirty of the most successful and 30 of the least successful programs in attracting women into engineering were examined, and an in-depth study of one institution (Georgia Institute of Technology) was conducted. Connelly and Porter (1978:4) concluded that two factors accounted for a substantial part of the institutional differences observed: "larger schools have tended to do better than small ones, and academically or socially elite schools have outperformed less-elite schools." They identified what they considered to be the two key underlying mechanisms:

- The Decision Support Hypothesis: Women considering engineering as an undergraduate major are doing something unusual. They are unsure about what the study or practice of the profession will involve: family, friends, and teachers will generally have little helpful advice; there are few women engineers with whom to talk; and the situation is changing rapidly. In short, engineering is a "high uncertainty" choice for a woman, and relatively more reassurance or "decision support" is needed to reduce this uncertainty.

The importance of support programs for women already in engineering school is documented by Davis (1965) and others. We are here arguing for a more general hypothesis, that support is needed before entry as well as during undergraduate training. The nature of this support will vary over time and by situation. Prospective students can benefit from perception that they are welcome and will get a fair chance. New frosh need campus-oriented support; seniors, job-oriented reassurance.

- The Positive Feedback Hypothesis: It appears that one of the most helpful factors in attracting women is to have a sizable number already. This helps in various ways: social and academic support groups on campus, involving both peers and more advanced students (often referred to as having a "critical mass" of women students); establishing a grapevine for course and career guidance; "role models," both older students and women faculty; informal recruiting, through contact with current high school students; attitude change, as high school and college faculty and counselors see women succeeding as engineering students; and so on. (pp. 5, 6)

Enriched Environments and Background Study

An interesting sociological approach to examining the enrichment factors associated with selection of nontraditional fields by women was conducted by Carol Auster (1984). She focused her Princeton doctoral dissertation under a Rockefeller Foundation/University of Illinois grant on men and women who were attending accredited U.S. engineering institutions. Her primary thesis was that "women in engineering would emerge from more enriched backgrounds than men in engineering," and her primary statistical tests were contingency table analyses and discriminant analyses. The following exerpts from her thesis are especially relevant:

> To some extent, the hypothesis that the women would emerge from a more "enriched" environment than the men is supported. For example, women were more likely than men to have highly educated parents with high incomes, fathers in engineering, mothers with full-time salaried jobs, and have spent most of their life in an urban area. Women also received overwhelming encouragement from those deemed most important and parents' encouragement was affected by some of the aforementioned social background factors. Other aspects of women's initial decision and continued commitment to engi-

neering seemed to further reflect the pioneering or nontraditional nature of their choice, including perceptions of the attitudes and abilities of women and men in the engineering program, and interest in engineering specialties and potential employers. In the initial decision making phase, the support of family, particularly parents, and the immediate milieu and academic success in high school were very important; however, the new immediate milieu, peers and professors, and engineering grade point average became important in continued commitment to engineering. (pp. xix-xx)

. . . Despite the many unanswered questions about occupational choice, many suggestions for those interested in recruiting more women into engineering are implicit in the findings of this research. Women must continue to take math and science courses throughout high school and college, be encouraged in those endeavors, and hopefully emerge with the confidence to pursue further work in these fields. Since those women are most likely to be the products of "enriched" backgrounds, educators could carefully tap into that group or further encourage the less likely candidates as a way of expanding the pool of potential women engineers. Further interest in engineering seems to be sparked by contact with those in the field. This suggests that science and engineering conferences which put women into personal contact with employed scientists and engineers should be continued, particularly if close relationships could be established between the working engineers and those potential engineers.

Once a woman decides to enter an undergraduate engineering program, she should be surrounded by people who offer support for such a decision and by professors whom she perceives rate the sexes equally for potential success in engineering. Furthermore, interaction with both male and female peers, especially discussions about engineering careers, seems to have a positive impact on these women.

The field of engineering may be shaped by the new interests brought to the field by the increasing numbers of women. Women seem particularly interested in people-oriented work functions and environmental issues. The interest in nature and the environment might help technologists recognize the need to work with nature, not conquer nature to the extent that the earth becomes uninhabitable. Eventually, men's and women's engineering specialties may reflect only individual and not learned gender-linked interests. (pp. 330-331)

Critical Mass, Role Models, and Unisex Programs

A number of studies and analyses indicate that the socialization process is greatly facilitated if there are a sufficiently large enough proportion and number of students having similar, albeit atypical, characteristics (for example, women, blacks, foreign nationals, or disabled). Somewhat related socialization factors are the importance of role models and the impact of special programs for target groups (programs for women only or unisex approaches). Unfortunately, there have been very few experimental or quasi-experimental studies in these areas of the research, and evidence is anecdotal, correlational, and "de facto."

Critical Mass. The "critical mass" theory has been proposed by a number of investigators (Byrne, 1985; Connelly and Porter, 1982; Lantz, et al., 1976). Although opinions vary considerably on what proportion or number constitutes a critical mass, the primary thrust of the argument is that until a sufficiently large enough number or proportion of women are enrolled in an institution, program, or course, the socialization process constitutes and remains a barrier. The resulting sex-role conflicts result in problems and hardships for women in science and engineering programs, which are inherently already difficult and demanding. However, when a critical mass is reached, many of the socialization problems are minimized, women recognize that there are others "in the same boat," and the resulting self-support groups are eventually institutionalized.

Role Models. The "role model" factor, a very common element in most programs designed to attract and retain women and minorities in science and engineering, is based on the premise that women can learn from other women "who have made it" or "are making it." Although early role model efforts focused on "stars" (women with unusually high achievement or endurance records), more recent role-model efforts have broadened the base considerably to include more "average" and even "struggling" women who have or are pursuing education and careers in science and engineering. A general consensus among those that have developed special programs is that role models are of critical importance. However, their impact on women's decisions to obtain science and mathematics educations was challenged recently in a report from the Federation of Behavioral, Psychological and Cognitive Sciences, which is appended to the report of the National Science Board's Commission on Precollege Education (1984:109):

> Research also has identified factors that influence students in selecting courses in mathematics and science, particularly among young women and members of minority groups. In addition to achievement in previous educational experiences, individuals are more likely to continue their mathematics and science education if they perceive these fields to be relevant to careers that are available to them, and if they have general interest in "things," rather than primarily in "people." Contrary to some popular belief, exposure to female role models in science and mathematics has been found to have little effect on young women's decisions to obtain science and mathematics education.

Perhaps some middle ground is in order i.e., programs should make use of a wide range of role models (not only women "stars," but average women achievers, dual-career couples, and male role models as well).

Unisex Programs. The "unisex or majority role" approach reflects efforts to facilitate the socialization process by focusing on institutions, programs, and courses where women constitute the primary total participants. A substantial number of studies indicate that women's colleges have produced a larger proportion of women scientists than coeducational institutions. Many programs targeted to women in engineering, math, and the physical sciences were developed to make women feel more "comfortable" in "hands on," remedial math, or experimental science courses.

Some experimental studies conducted on male-female ratios have provided relatively unclear or nonconfirmatory evidence that same-sex or balanced-sex courses are most effective. One such study conducted at Purdue University utilized a "hands on" laboratory setting (one "all women" section and one "balanced" with equal numbers of men and women). No statistical differences in cognitive and affective variables were observed from both summative and formative evaluations. Anecdotal results indicated that in the all-women's section, there was a "more relaxed and less threatening atmosphere," but that there was a more "realistic" and "gender helping" atmosphere in the balanced-sex section. At the end of that study, the overwhelming majority of women and men, including participants in experimental and control groups, strongly endorsed integrated or "gender-mixed" lectures, laboratories, and counseling (LeBold, et al., 1983).

Retention of Women in Science and Engineering Programs

Research on college attrition has generally indicated that cognitive factors, especially early college grades, are the primary factors affecting retention rates. In addition, a significantly large number of studies indicated some gender differences. Generally, these have indicated that academic achievement may be somewhat more relevant to retention and attrition for men and personal factors more relevant for women. This section focuses on two comprehensive national studies of engineering retention and one comprehensive institutional data base.

Female Engineering Students: Attitudes, Characteristics, Responses to Engineering

This study, conducted under a grant from NSF, employed a longitudinal data collection rationale; however, it was funded only for two years and long-range institutional data were limited. Of special relevance was the data collected on engineering retention. Ott (1978) analyzed the retention rates of women and men in engineering at 42 schools. She estimated that the retention rates in engineering until the beginning of the sophomore year were 73 percent for men and 68 percent for women; women were more likely to be internal transfers, and men were more likely to leave for academic reasons or as voluntary withdrawals. She also found that academic achievement in high school was positively related to engineering retention for both men and women. Also, women who remained in engineering, compared to women who left, were more apt to have fathers who were college graduates, to be "Caucasian," to have done homework in high school, and to have parents who stressed the importance of attending college.

National Engineering Career Development Study

This study examined a number of factors associated not only with the educational and career development of beginning men and women engineering students, but also with the educational and career development of engineering men and women after graduation. Of special relevance to this report was the data collected on engineering retention under grants from NSF and the EXXON Education Foundation.

Shell, et al. (1985), studied engineering and university retention at 20 U.S. engineering institutions as part of this study. They found that 55 percent of the female and 74 percent of the male first-year students in 1981 were still in engineering in their third and fourth years. They also found that women were more likely to be internal transfers than were men (19 percent versus 15 percent, respectively). The primary factors positively related to engineering retention for both men and women were academic performance during the first year in college; SAT-Math scores; and self-perceptions of math, science, and problem-solving ability. These same variables were found to be positively related to retention of men and women in engineering both when each gender was analyzed separately and when men and women were combined in a single analysis. Other factors positively affecting engineering retention included the selectivity of the institution attended, high Nuclear and General Engineering Interest Inventory Scores on the Purdue Interest Questionnaire (PIQ), high school rank, and precollege grades in math and science. Some factors negatively related to engineering retention were (1) job values that stressed job comfort, income, job flexibility, and routine work and (2) high Management Interest Inventory scores on the PIQ.

Purdue University's Studies of Engineering and University Retention

Purdue University has been monitoring university and engineering retention using longitudinal data bases for more than 25 years. During the last two decades, the university has focused considerable attention on 10-year longitudinal studies of engineering retention (do first-year engineering students persist and eventually graduate in engineering?) as well as university retention (do engineering students persist and eventually graduate in engineering and/or non-engineering fields at Purdue?). Researchers have found that short-term attrition studies that examine engineering or university retention rates through the sophomore year are often misleading; even studies that examine graduation rates after four years (or eight semesters) grossly underestimate the graduation rates.

Figure 2 provides a graphical perspective on the importance of longitudinal data in examining university and engineering retention and graduation rates. Purdue's women engineering students who began their studies in September 1976 were tracked using computerized student records every semester for 10 years (note that most university and engineering attrition occurs during the first and second years). Most of the engineering students who were still attending Purdue after five or six semesters (junior year) eventually graduated with baccalaureate degrees. Figure 2 also indicates that estimates of graduation rates after four years (or eight semesters) grossly underestimate the longer-term graduation rates. Stopping out instead of dropping out also is fairly common for an increasing proportion of students, and many students participate in special work study or cooperative programs that result in undergraduate time periods greater than four years (or eight semesters).

Retention data for men and women who began their engineering studies at Purdue are very similar (see Figure 3). A slightly lower percentage of women than men is retained in engineering, but a slightly higher percentage of women who entered in engineering is retained in the university and eventually graduate. Tests of the significance of the differences in the percentages of men versus women who are retained in or graduate from engineering or who are retained in and graduate from the university support the null hypothesis of "no statistically significant differences."

This rich data base, which includes samples annually ranking from 1,000 to 1,500 students who have been followed longitudinally for 10 years, provides the basis for the following observations:

- University and engineering retention rates improved significantly during the 1970s.
- Engineering retention improved significantly due to improved admissions and initial course placement, special programs designed to improve retention, and grade inflation.
- Cognitive variables are normally better predictors of engineering and university retention than non-cognitive variables including gender, socioeconomic status, interest inventories, personality measures, and attitude measures.
- Precollege variables are of less value in predicting engineering and university retention than college variables. Multiple regression, discriminant analysis, and other multivariate techniques usually indicate that precollege variables have negligible predictive value when college variables such as grades are included.
- Essentially the same variables predict engineering and university retention both when analyses are made separately for men and for women and when both groups are combined. However, women who transfer to nonengineering fields or withdraw from college usually have higher college grades than men who transfer or withdraw.
- Engineering retention seems to be primarily related to academic performance at the college level (grades) and, to some extent,

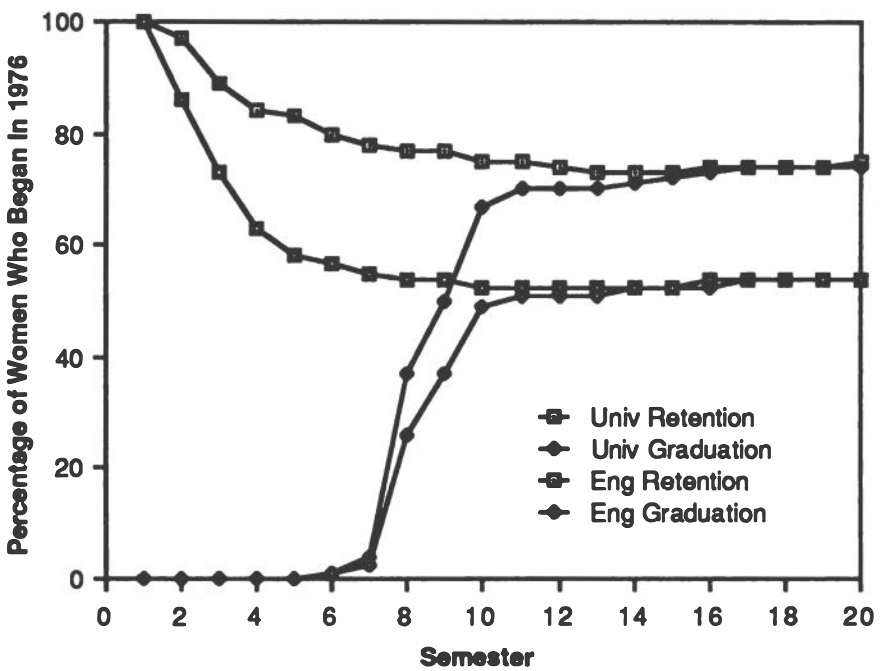

Figure 2 University and engineering retention and graduation rates of women, Purdue University, 1976.

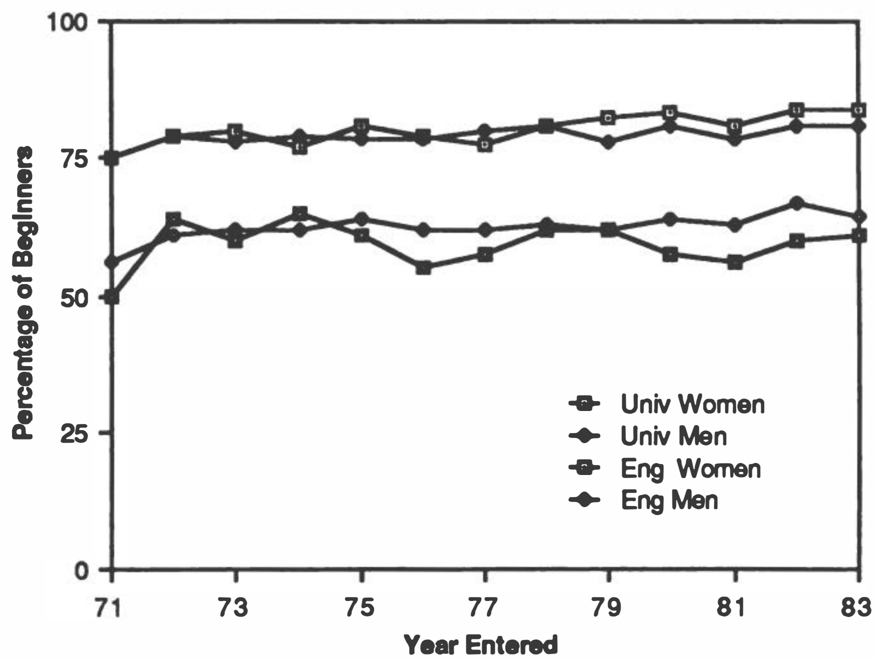

Figure 3 University and engineering retention rates (after six semesters), Purdue University, 1971-1983.

interest in the field and career content. Economic factors related to the supply and demand of engineers and scientists in particular fields also influence transfer and retention rates.

Graduate School and Related Financial Aid

Although this paper has focused on undergraduate programs, decisions made at the undergraduate level are often critical in preparing and encouraging science and engineering students to pursue degrees beyond the baccalaureate level. Until recently, women were not encouraged to the same extent as men to pursue graduate studies in science and engineering and to seek and to attain federal support.

Data on graduate enrollment and support (NSF, 1983) indicate that women are less likely to receive federal and institutional support than men and more likely to be self-supporting. Although considerable efforts have been initiated in recent years to encourage more women to apply for federal and university fellowships and assistantships, National Research Council data indicate that fewer women apply for such assistantships and that the selection process may require further review to insure equitable treatment. The selection process for graduate admissions, financial support, and awards relies primarily on Graduate Record Examination scores, rather than on college and major grade-point index, and the recommendation of male faculty, who may not support equitable treatment for women in science and engineering. Potential discriminatory practices must remain a matter of concern and certainly merit careful analysis and study.

Although institution-wide programs directed at providing more equitable graduate opportunities are important and necessary, more effective programs within institutions may require more grass-roots efforts at the college or departmental level. For example, the College of Engineering at the University of California, Berkeley, recently prepared an affirmative action report on graduate education (Pister and Humphreys, 1986). The report recommended a comprehensive approach that begins with recruitment but also recognizes the need for retention, evaluation, encouragement, commitment, and even advocacy. It documents the actions and policies required to meet the challenge to develop, implement, and institutionalize an effective graduate program for women and minorities.

Major Findings and Implications

The major findings and implications of this report on undergraduate education for women in science and engineering can be classified into two major areas: (1) programs and policies designed to increase the number and proportion of women in science and engineering and (2) areas of research and study that are needed to provide more definitive information useful for developing programs and policies that will lead to more equitable opportunities for women in engineering and science.

Program Elements

Some of the factors influencing the career choices and career development of women can only be affected by slowly evolving changes in society and culture. However, significant impact on other factors has been accomplished through direct interventions aimed at the individual as well as indirect strategies aimed at teachers, counselors, parents, and employers. Programs have been developed at colleges and universities to influence positively the number of women selecting and successfully completing science and engineering programs. Directories and books (Aldrich and Hall, 1980; Bogart, 1984; and Humphreys, 1982) describe in some detail these programs, many of which have carried out extensive evaluation of individual interventions. In addition, a comprehensive evaluation of women in engineering programs throughout the country is presently under way by Susan Schwartz at the Stevens Institute.

A variety of elements constitute effective programs designed to increase the pool of women in nontraditional fields where they are underrepresented. Fragmented programs that focus on single issues are often ineffective; and a recruitment program that either ignores retention or only focuses on merit awards or an occasional career day are not likely to be very effective. A comprehensive institutional program designed to increase the pool of women in engineering or computer science should include at least four program elements: (1) recruitment, (2) retention, (3) employment, and (4) evaluation. At the undergraduate level, for example, a recruitment program might include the following: high school visitations; education and career information; teacher-counselor conferences; merit awards, scholarships, and financial aid; summer programs; academic year programs; personal follow-up programs; and parent-student information sessions. Similarly, an effective retention program might include orientation programs, special courses and seminars, peer tutoring, recognition awards and events, exit interviews, educational and career counselling, cooperative and summer job programs, and student organizations, e.g., Society of Women Engineers.

Since the overall plan is to eventually increase the pool of women in science and engineering careers, an effective program at the undergraduate level might also focus on the following:

- Employment: invitations to prospective employers, summer internships and cooperative programs, job search and career days, resume preparation, interviewing techniques, job listings, and college placement services.
- Graduate School: undergraduate teaching or research assistantships, graduate student and faculty mentorships, invitations for department seminars, graduate school information sessions, campus visits by faculty representatives from leading advanced degree institutions, and dissemination of information on graduate school admissions and fellowships.

Comprehensive programs also have a synergetic impact, both within program elements and between program elements.

The final element in developing a comprehensive program at the undergraduate level would include an evaluation program that might include pre- and post-surveys for special programs, exit and graduate interviews or surveys, follow-up studies of graduates, systematic interviews and surveys of students, experimental and quasi-experimental studies, student data-base information systems, cognitive and affective testing, and faculty and counselor feedback programs. It is important to note that the evaluation element should be an integral part of the overall program; individuals and staff responsible for evaluation should be included in the planning and operation of an effective program. Similarly, evaluation data collected for its own sake without providing important and timely feedback is of limited value, even though they may contribute to researchers' fields of expertise and have some merit in their own right.

Future Areas of Research on Gender Equity in Science and Engineering

Four areas of future research are especially relevant to programs designed to facilitate gender equity in science and engineering: (1) data bases, (2) admissions, (3) retention, and (4) education and career development program evaluation.

Summary

The following generalizations can be inferred from the material presented:

- Significant increases in the pool of women who are qualified and interested in education and careers in science and engineering are needed.
- Increases in the pool of qualified women interested in science and engineering can be achieved by a combination of societal, institutional, disciplinary, and individual efforts.
- To achieve more equitable representation of women in engineering and science, special attention at the undergraduate level should focus on engineering and the physical sciences, the two major areas where women are significantly underrepresented. Within engineering, the disciplines in which women are most underrepresented at the undergraduate level include three of the five largest and well-established disciplines--mechanical, electrical, and civil engineering--as well as some of the smaller but significant disciplines including aerospace, nuclear, and petroleum engineering. In the physical sciences, physics and astronomy seem to be the primary fields quiring attention.
- Significant progress has been made ir he past decade in encouraging a larger percentage of coll -bound women to enroll in math and physical science in high school, but the gap between women and men in precollege preparation remains large. A new area of increasing importance is the potential development

of gender inequities in the precollege computer backgrounds of women entering science and engineering.

- There is some evidence that a critical mass can have a synergetic impact that facilitates not only recruitment, but also retention, career choice, and career development. Role models and programs designed to meet the special needs of women are also effective.
- Additional factors that are important in increasing the percentage of women in engineering and science are institutional in nature. Private institutions, traditionally black colleges, and selective institutions seem to have been more effective than public, predominantly white, and less-selective urban institutions.
- Institutions with strong comprehensive and administratively supported programs that stress not only recruitment, but also retention, graduate school, and science and engineering careers seem to be more effective than programs that focus on only one or two areas and are not supported by administration and faculty. The development of comprehensive institutionalized programs may be the key element necessary to ensure full participation of women in science and engineering.

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DISCUSSION: WOMEN IN ENGINEERING AND SCIENCE

Susan F. Chipman

LeBold provides much detailed information to flesh out the obvious fact that women are poorly represented in physical science and engineering fields. He points to changes toward more equitable representation that have occurred in recent years but still leave engineering enrollments with a ratio of about six males to every female. Fields such as mathematics, biology, and psychology are characterized as having reached nearly equitable representation. As a psychologist, I feel obliged to point out that the label "psychology" covers the combination of a large helping profession with a relatively much smaller scientific research field. Although the representation of women in scientific psychology has certainly improved, it is unlikely that a state of equitable representation has been attained. As a research manager, I am aware that certain subfields of scientific psychology still have very few women in them.

LeBold notes that the trend toward increasing enrollments of women in engineering has leveled off in the 1980s. It is important to recognize that there was every reason to think that this would happen and to think that further increases in female engineering enrollments may be difficult to achieve. Dunteman, et al. (1979), did extensive analyses to model the career selections of participants in the National Longitudinal Survey, a study of people who finished high school in 1972. These analyses showed that basic interest patterns--roughly characterized as an interest in "things" as contrasted to an interest in "people"--were very important in predicting the likelihood that a science or engineering major would be selected. There are large sex differences in those interest patterns, and they can go a long way toward providing an explanation of the sex differences in major selection. However, despite analyses in which many variables were either included--such as the number of high school math and science courses--or explored for explanatory power--such as family formation plans, Dunteman, et al., still found unexplained negative effects of being female on the likelihood that a science or engineering major would be selected.

These negative effects probably represent the barriers of sex-stereotyping. It seems likely that the increased enrollments in the past decade mean that those barriers have dropped: if we were to do a similar modeling of the selection of major fields using data from a recent cohort, perhaps the "unexplained" sex differences would be gone. However, it seems certain that the sex differences in interest patterns will remain an important factor determining continuing sex differences in engineering enrollment. My own experience reviewing research on the issue of female enrollment in high school mathematics (Chipman and Wilson, 1985) also suggests that early interest patterns and related career expectations determine enrollments in the high school math and science courses, not that course enrollments determine later career choices.

High school workshops designed to encourage interest in scientific and engineering careers are fine, but it is almost certain that they are "too little, too late" to have a very significant effect. Indeed, we have very little understanding of what it would take to alter those basic interest patterns. And--despite the disadvantage that seems to accrue to those who care for people in our society--one might question whether it is really a desirable goal to attempt to reduce the proportion of people in our society who are primarily animated by an interest in and concern for people.

A major focus of LeBold's paper, however, is on what determines whether people stay in engineering studies once they have begun. For these people, these women, the selection hurdle of appropriate interests has been overcome. Social variables--such as teacher encouragement, mentoring, and financial variables--seem to be important factors at this point. Not surprisingly, for both sexes, cognitive variables are the big determinant of success and persistence in engineering studies. However, there are signs that the social variables must still be working to the disadvantage of women students in engineering. LeBold reports that men are somewhat more likely to attrite for academic reasons, whereas women are somewhat more likely to transfer to another major and successfully complete college. At Purdue, however, the overall picture is one of negligible sex differences in the likelihood of completing engineering studies once they are begun.

LeBold also considers the idea of special single-sex programs for women students, reporting on an experimental program of his that did not prove popular with students and did not have any effect on cognitive or affective outcomes with respect to the subject-matter (LeBold, et al., 1983). Because women scientists have come, disproportionately, from women's colleges, people often suggest that a single-sex environment would be helpful in increasing women's participation in scientific and technical fields. Although I have not thoroughly reviewed the issue, I have never seen a really good study showing the positive effects of women's colleges. In particular, I have not seen one that controls for the effects of social class and economic status.

LeBold cites Auster (1984) as finding that women in engineering were more likely than men to have highly educated parents with high incomes. Scientists generally tend to come from relatively advantaged backgrounds, and this is likely to be still more true for women scientists, given the lesser willingness to invest in the advanced education of women that both parents and institutions have shown. It is not surprising, therefore, that the Seven Sisters colleges would have a better than average record in producing women scientists. In the absence of strong evidence to the contrary, I tend to share the view of LeBold's students that an integrated educational environment is more realistic preparation for work in an integrated world.

However, whether or not there is research to support the conclusion, it seems only prudent for a young woman to select an engineering program like LeBold's program at Purdue, where women are reasonably well represented and supported by an encouraging institutional environment.

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WOMEN GRADUATE STUDENTS: A LITERATURE REVIEW AND SYNTHESIS

Lilli S. Hornig

Introduction

The purpose of this paper is to review the literature on women graduate students in science and engineering (S/E), focusing on the period since 1970, in an attempt to identify major trends in women's participation and the major factors that are responsible both for the observed changes and for certain differences from the male pattern of participation. At the beginning of this period, the concern of most studies of women in graduate programs focused on equity issues, with secondary attention to the social utility of advanced education for women. By the mid-1980s, however, the declining interest of white men in S/E training and careers has added more specific public-policy concerns about the future adequacy of the S/E human resource pool to many investigations of women's participation. A similar shift of focus, from the earlier emphasis on women's attitudes and personal judgments toward a more dispassionate examination of data on actual outcomes, appears to be still in progress. The dominant theme remains concern with what is variously described as "underrepresentation," "low participation," or "lack of interest" by women in S/E--despite the fact that certainly by the end of this period the number of new women S/E Ph.D.s produced each year is well over three times that of humanities degrees--5,119 total doctorates in the sciences in 1985, compared to a total of 1,489 in the humanities (Coyle, 1986:51). Additionally, marital and parental status are often invoked to explain some of the gender differences in graduate study, and in later career outcomes, without much foundaton in empirical findings.

Sex differences vary markedly among fields, and it is therefore essential to analyze most of the issues separately for the various disciplines to gain an understanding of the actual situation. Unfortunately, many empirical studies account inadequately (if at all) for field differences and thus tend to generalize their findings beyond the level sustainable by the underlying data. In particular, very significant differences exist in such institutional structures as financial aid mechanisms for different disciplines, and these account for different patterns and timing of graduate study in, say, physics, engineering, life sciences, and psychology. These underlying field differences affect both men and women; since the distribution of students by sex varies among these fields, a study that compares, for example, the timing of graduate study in "the natural sciences" by sex would produce an apparent sex difference that disappears when field-specific data are used.

The problems broadly referred to as "career choice" are traditionally of great interest in women's education. Properly speaking, they are no longer significant at the graduate level if the meaning is taken to be "field choice"; that choice is typically made several years earlier in the case of S/E careers. What is relevant for graduate education is the level of career aspirations in the field already chosen. Traditional interpretations of women's participation in S/E suggested, well into the 1970s, that the length and rigor of graduate study in these fields were poorly suited to women's life course (even though more traditionally feminine fields characteristically require much longer graduate study) and that women's aspirations were more cultural than professional. In contrast, the underlying assumption of the present discussion is only that women, like men, undertake graduate S/E study (and probably all graduate and professional study) as career preparation rather than simply as a form of intellectual enrichment.

Minority representation in S/E is generally small except for high Asian participation in engineering, physical, and biological sciences, and women of the various subgroups tend to follow a field distribution pattern similar to that of majority women. As a group, however, and again excepting Asians, minority women are more likely than white women to obtain Ph.D.s compared to similar men. Although these statistical patterns have been evident for some years, empirical studies that address combined race and sex differences have not been carried out. It should be noted that trends in minority participation are more difficult to trace than those for women, since separate data for minorities were not collected before the mid-1970s; in many instances it was illegal to collect such data.

The year 1970 serves as an important reference point, being the last in which it was legal for institutions to maintain different policies by sex with regard to admissions criteria, financial aid awards, residential requirements, and so on. Revised Order Number 4 in December 1971 inaugurated the era of legally mandated equal opportunity for women in higher education, and the Higher Education Affirmative Action Guidelines issued in October 1972 produced many of the changes documented here.

The Statistical Outlines

Graduate Enrollments and Degrees Since 1970

The basic statistical framework that outlines the enormous changes in women's S/E participation in the past 15 years consists of two detailed surveys, one of graduate enrollments in full-time and part-time programs at doctorate-granting and other institutions carried out by the National Science Foundation (NSF) and a second that is an essentially complete annual census of doctorate recipients carried out for

NSF and other federal agencies by the National Research Council. Information in both surveys is disaggregated by sex, race/ethnicity, citizenship, and discipline; and special tapes and tabulations are available. Data from these surveys continue to show some progressive underrepresentation of women among S/E graduates in most fields at progressively higher degree levels in the mid-1980s, although the disparities relative to men have greatly diminished since 1970. Thus, women's share of baccalaureate S/E degrees--the necessary precursors of graduate study--rose from 26 percent in 1970 to almost 38 percent in 1983, representing a 68 percent growth rate for women compared to a 2 percent decline for men during this period. The number of women earning S/E master's degrees rose by 99 percent in that time, and the number of those earning doctorates had increased 181 percent by 1984 (NSF, 1986:26).

Although women's participation is most often expressed as a percentage of total degrees, probably partly because that is a relevant consideration in determining share of employment, the use of such proportions for analytical purposes is frequently misleading because men's participation has also changed rapidly during this period. The rate at which S/E baccalaureate degree-holders enter and complete graduate training has declined for both sexes since 1970, but much faster for men than for women [National Research Council, Committee on the Education and Employment of Women in Science and Engineering (CEEWISE) 1979:21; NSF, 1986:173-174]. Both sexes reached their lowest Ph.D. attainment rates in 1980 and 1981 (6.3 percent for men and 4.4 percent for women) and have shown a slow increase since then (NSF, 1986:173-174). Since the numbers of women S/E baccalaureates were growing rapidly while those of men stayed level or decreased, the net result was a convergence of graduate participation patterns. Overall, the number of S/E doctorates granted to women annually has grown from 1,626 in 1970 to 5,119 in 1985 while the corresponding numbers for men are 16,717 and 14,045 (Coyle, 1986:48-51; NSF, 1986:171-172), yielding an increase in women's share of these degrees from 9.2 percent to 26.7 percent.

Summary figures for male-female comparisons for S/E as a whole distort the actual situation because about one-quarter of all baccalaureate S/E degrees in engineering are awarded to men and less than 10 percent to women, yielding comparable disproportions at graduate degree levels (NSF, 1986:169-170). Since engineering is such a large field, however, these low proportions in fact represent quite large numbers of women. In 1985 about 11,000 women earned bachelor's degrees in engineering--a figure that compares with about 15,000 in English, the academic field considered to be quintessentially feminine. The increases in numbers of women engineers have been very rapid since 1970, when fewer than 350 graduated. Consequently, the proportion of women doctorates, which is based on the number of baccalaureates eight years earlier, appears small--5.2 percent in 1984 (Coyle and Syverson, 1986:38)--compared to the proportion of baccalaureates in the same year. In fact, however, it should be compared with the proportion of women baccalaureate engineers who graduated in 1976, which was 3.7 percent (Vetter and Babco, 1986:168). These figures

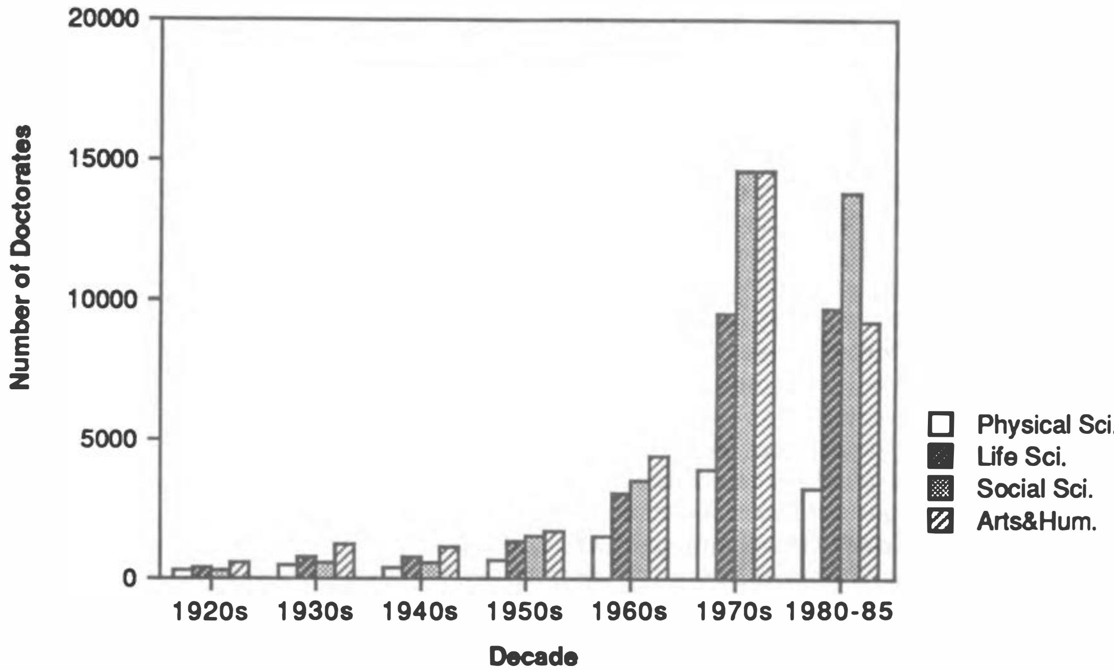
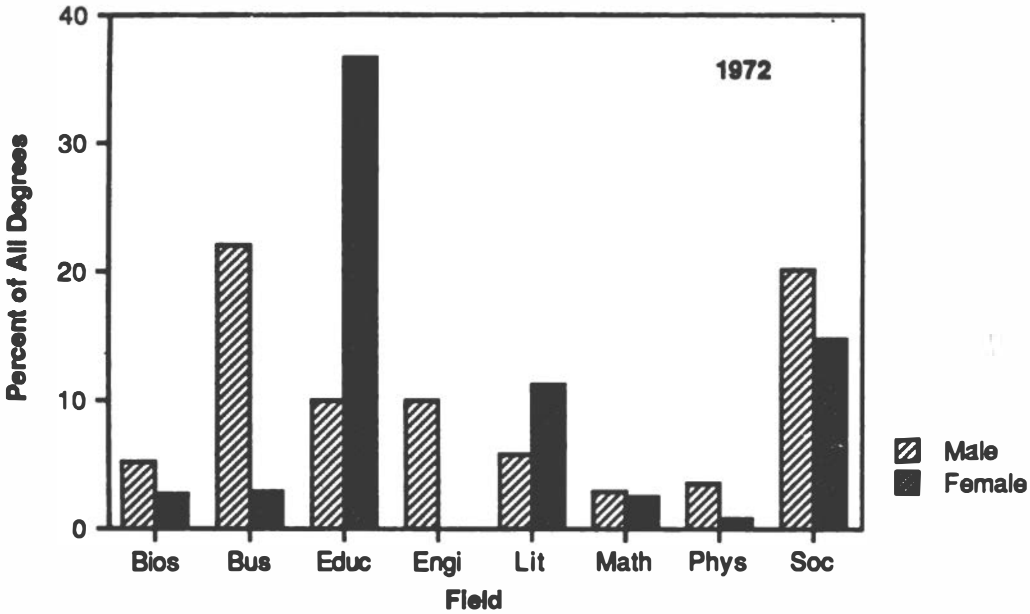


Figure 1 Number of doctorates awarded to women, by decade and field group, 1920-1985.

yield a higher rate of persistence to the doctorate for women engineers than for men, an issue which is discussed in more detail below.

Within the broad area of the sciences, there are also considerable sex differences in the distribution among fields. Male Ph.D.s are relatively concentrated in the engineering, mathematical, and physical (EMP) sciences, which together account for almost half of all science doctorates granted to men. In contrast, this field group currently accounts for less than one-fifth of female science Ph.D.s, while almost half are in social and behavioral sciences. The differences in these proportions, however, are less marked now than they were in the early 1970s; as more women students became better prepared in quantitative fields, a slow rise occurred in the proportion of EMP doctorates. These trends are depicted in Figure 1, which is based on data from the National Research Council's annual Survey of Earned Doctorates.

Shifts in graduate field distributions are foreshadowed by undergraduate majors. Since about 1970, the single most striking change in women's undergraduate major fields is a massive shift out of education and into business; in the remaining fields, a gradual redistribution appears to be in progress with the more traditional areas like humanities and social sciences losing students to the natural sciences and engineering. These trends are shown in Figure 2. Based on these numbers, continued moderate growth can be expected for women S/E doctorates in all fields except social sciences for the remainder of the 1980s.



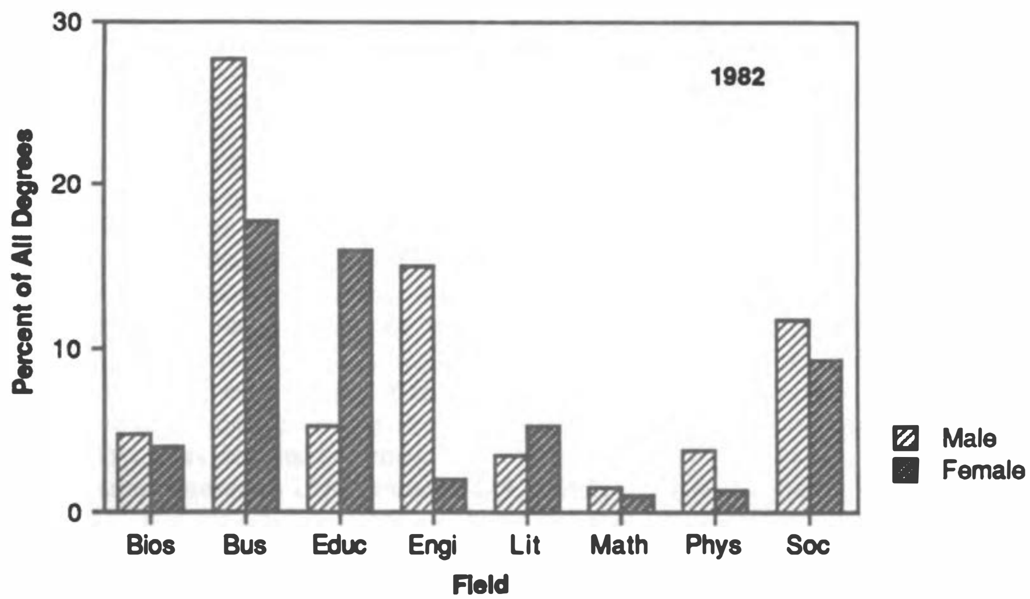


Figure 2 Bachelor's degrees in selected fields, by sex, 1972 and 1982.

Attrition and Persistence

An undergraduate major in a given field of science (as distinct from engineering) does not necessarily signify a commitment to a high-level professional career in that field for either women or men. Many students of both sexes decide to pursue jobs rather than further study on completing a baccalaureate. Such a decision is not necessarily correlated with ability and undoubtedly has some relationship to economic status and goals. Overall, higher proportions of women than men do not attend graduate school in most science fields.

Students who do continue can be categorized according to type of institution (Ph.D.-granting or master's only), type of control (public or private), and part-time or full-time attendance. Such categories are useful in assessing sex differences in persistence because the proportions of men and women vary among them; women are generally less likely to be full-time students, more likely to enroll in master's-only institutions, and more likely to be in public universities. These distributions are surveyed periodically by NSF and reported in detail in its series, Academic Science/Engineering: Graduate Enrollment and Support. Disproportionate enrollment of women in lower-prestige and/or lower-cost institutions is noted by various authors in various contexts (Berryman, 1985; Carnegie Commission on Higher Education, 1973:85; Feldman, 1974:15-16; and Roby, 1973:41). Although Feldman points out that women graduate students are relatively well-represented in medium-quality and low-quality colleges, this finding is not especially pertinent to S/E students, since virtually all graduate programs in such institutions are in education or other human service areas. Numerous other reports (CEEWISE, 1979; 1983:2.2-2.3; Cole, 1979:213; Feldman, 1974:15; Folger, et al., 1970:285) note the remarkably even distribution of women S/E doctoral graduates among different quality groupings of institutions, emphasizing that, field for field, women are as likely as men to receive their doctorates from distinguished or strong departments and that this has been true over a long period.

Among these various studies, only the reports of CEEWISE disaggregate the data on quality of doctoral department by field. Others, notably Cole's, use proportions averaged over all fields, which can be misleading because the field distributions differ by sex. However, CEEWISE found significant differences in only four fields: women were overrepresented in highly rated departments in microbiology and psychology, and men were overrepresented in similar departments of physics and math during the period 1970-1980 (1983:2.7).

These recent data represent a significant departure from the traditional situation in which women had much higher dropout rates than men. A much-cited study by Mooney (1969) investigated the graduate school and degree histories of nearly 7,500 men and women who had held Woodrow Wilson Fellowships between 1958 and 1963. By 1966 the attrition rate for the women science students in this group was twice that for men (54 percent versus 26 percent). Roughly similar results were obtained in a study by Joseph (1971), which followed up the first five classes of National Defense Education Acts Title IV fellows. Mooney's analysis was reviewed at length by Patterson and Sells (1973) in a chapter of Rossi and Calderwood's Academic Women on the Move, a volume that has served as one of the basic texts of modern studies on academic women. A study similar to Joseph's was carried out by Harmon (1977), spanning a longer period (1959-1973) and also finding substantially higher attrition for women than for men, as well as much poorer subsequent career outcomes.

A problem alluded to by some authors but not resolved is how to distinguish between sex-differentiated rates of entering any graduate program (or, specifically, a doctorate program) and rates of leaving such a program without completing any degree. Information available on graduate enrollments in general (from NSF and the Council of Graduate Schools) does not discriminate among those planning master's or doctorates or even those not registered for any degree (Garet and Butler-Nailin, 1982:33ff). It is possible to distinguish, by sex, enrollments in master's versus doctorate-granting departments, but many students in the latter may only be enrolled for a master's and many students from master's-only departments may subsequently pursue a doctorate elsewhere, so the distinction has limited value. Overall, as a report to the U.S. Congress notes, the proportions of women among S/E baccalaureates and among graduate students are almost identical, so that no significant attrition takes place in entering advanced study [Office of Technology Assessment (OTA), 1985:117-118]. Only two major departures from this rule occur: in mathematical sciences women were 37 percent of baccalaureates and 27 percent of graduate enrollments in 1982, and in life sciences they were 40 percent of B.A.s and 52 percent of graduate students. The latter figure probably reflects the very high interest by women in the various health-related professions rather than in doctoral programs in biosciences.

The OTA report, citing Malcom (1983), states that "the problem appears to be with persistence in graduate school" (1985:118). Comparison of their figures with degree attainment rates (calculated from NSF 1982, 1984, and 1986) corrected for field-specific Ph.D. completion times (first derived by CEEWISE, 1983:1.11-1.12, and termed "parity indices"; see also Russell Sage Task Force) allows a somewhat more detailed description to emerge. A sample calculation using NSF degree data (NSF, 1986:167-172) shows that 22 percent of the 1977 women baccalaureates in physical sciences earned master's degrees in 1979 and that 11 percent of the original group earned doctorates in 1984; for men the corresponding figures were 30 percent and 16 percent. Alternatively, women obtained 20 percent of physical sciences bachelor's degrees in 1977, 18 percent of master's in 1979, and 15 percent of Ph.D.s in 1984. Mathematics shows a much greater loss, from 35 percent of baccalaureates to 15 percent of doctorates. In engineering, however, a marked increase in representation occurs, going from 3.7 percent of bachelor's degrees in 1976 to 5.2 percent of doctorates in 1984; women engineers in that period were therefore much more likely than men to persist to the doctorate.

Factors Affecting Continuation and Persistence

Broadly speaking, only three factors determine, in some combination, a college student's decision to continue to an advanced degree: ability, access, and motivation. Each of these factors may in turn be affected by a rather large number of demographic, socioeconomic, psychological, and possibly genetic variables. Direct causal connections between any of these variables and success in graduate study have not been established, although some highly suggestive correlations are well recognized. Among these is the fact that being female lowers a student's chances of completing a Ph.D. in nearly all fields, as shown above. Similarly, lack of financial support is likely to lead to abandonment of study, or to prevent its being undertaken in the first place. Mooney's data on Woodrow Wilson Fellows as recomputed by Patterson and Sells (1973:89) showed dramatic decreases in dropout rates when <u>any</u> second-year support was offered.

The tacit assumption of most studies on women in graduate programs is that the observed sex differences must be related either to ability or to motivational factors; access issues are not even mentioned by most authors, with rather few exceptions (CEEWISE, 1983:1.13; Hornig, 1984:34; National Commission on Student Financial Assistance 1985:32, 80; and Russell Sage Task Force). In particular, many studies focus on marriage and parenthood as the putative cause of women's lesser success without considering the role of mundane factors such as money or job prospects in a woman's decision making.

Ability

As a general rule and across the spectrum of academic fields, women compile significantly better performance records than men at all levels of schooling, including graduate study (CEEWISE, 1979:23-26; Feldman, 1974:18; Harmon, 1965:28-32; Patterson and Sells, 1973:83). Among entering college students who plan on S/E majors, far larger proportions of women than men earned "A" averages in high school, with the greatest advantage (59 percent of women versus 38 percent of men) occurring in engineering and the smallest (29 percent of women versus 24 percent of men) in social sciences (NSF, 1986:163). However, these trends are not uniformly reflected in scores on standardized tests, at any level. On the Graduate Record Examination (GRE), women S/E students do somewhat better on the verbal and analytical tests but significantly less well than men on the quantitative portion. These discrepancies, which occur to roughly the same extent on other standardized tests, have so far eluded complete clarification.

Possible sex differences in true mathematical ability, as distinct from level of achievement, have been the subject of hundreds of studies over the last few decades, but no conclusive or unambiguous results have been reported. Many of these findings are reviewed in <u>Women and the Mathematical Mystique</u> (Fox, <u>et al.</u>, 1980). Sex differences in performance on certain tests of mathematical reasoning are quite large among precocious children, but social and cultural causes for this effect, rather than biological ones, can by no means be ruled out. An analogous problem exists with respect to racial differences, where, for example, the lower scores of black and Hispanic children are customarily ascribed to socioeconomic differences, although such an explanation takes no account of the uniformly higher scores of Asian children.

Sex differences in mean quantitative scores on the Scholastic Aptitude Test (SAT) are largely explained by differences in high school course-taking (Fennema, 1980) and also correlate with demographic and socioeconomic differences among the pools of male and female test-takers (Hornig, 1984:34). Similar data for the GREs are not available, and it is therefore not possible to sort out these issues completely. However, the large, rapid recent increases in women's level of mathematical preparation and in the number of women pursuing quantitatively-based fields suggest the absence of decisive genetic differences.

Although facility in mathematics is undoubtedly necessary for most science fields, the direct relationship between mathematical ability and ability in various science and engineering fields remains largely unexplored. In particular, it is not known whether the kind of mathematical precocity tapped by Stanley and coworkers (Fox and Cohn, 1980) and demonstrated by so many more boys than girls is a factor in later scientific ability and performance, although it seems intuitively obvious that it should be so. Less obvious is whether the score differences in the GRE represent differences in ability or in college course-taking, an issue which remains to be studied for this set of tests. On the SATs, however, it is known that most of the difference disappears when course-taking is held constant (Fennema, 1980:81-82). It is also not known for certain that the residual discrepancies between women's performance in coursework and on standardized tests are not due to some bias inherent in test construction.

Mean score differences by sex are not constant over time and have been diminishing quite rapidly in recent years. For physical science majors, the score differences on the quantitative GRE decreased from 40 to 33 points (out of a possible spread of 600) between 1979 and 1984, for mathematical scientists from 46 to 37, for engineering majors from 58 to 10, and for biologists from 49 to 29. For behavioral and social science majors, however, the difference increased during this period, from 43 to 48 and 55 to 62 points, respectively (calculated from NSF, 1986:165-166). These changes strongly support the interpretation that women's traditional deficit in math is primarily the result of differential preparation. In 1984 the highest mean quantitative scores for both sexes were in engineering, followed by mathematical, physical, and biological sciences and then by behavioral and social sciences. The total range for mean scores is nearly 200 points, from 667 to 476 (NSF, ibid.). Due to the lack of correlation between women's grade-point averages (GPAs) and test scores, the latter consistently underpredict women's actual performance. No evidence exists, however, to suggest that this effect is given consideration in admissions decisions.

Certain proxy indicators of ability, in addition to measures such as GPAs and test scores, are widely used in subjective appraisals of graduate students or new Ph.D.s--for example, in consideration for academic appointments or other jobs. One such indicator, receiving a doctorate from a highly rated department, has already been discussed. Another is being relatively young at receipt of the degree, as are related ones such as short degree-completion times. These assessments have been subject to much misinformation concerning women. Older studies typically compared male and female completion times averaged across all fields, a spurious comparison that yields long times for women because there are relatively higher proportions of women in the humanities and in education. These fields are characterized by long completion times for both sexes, a factor generally related to the amount of financial support available (compare Coyle, 1986:20-28; Hornig and Ekstrom, in preparation; Syverson, 1982:13-14, 32-33). In most physical, natural, and mathematical sciences as well as in engineering, women complete their Ph.D.s as fast as men or faster (CEEWISE, 1979:38; 1983:2.3, 2.8-2.9; compare the National Research Council's Summary Report series, especially 1985). Notable exceptions occur in two fields, computer sciences and health sciences, which have been shown to have especially unfavorable graduate financial support patterns for women but not for men (National Commission for Student Financial Assistance, 1985:32, 80; Russell Sage Task Force; Syverson, 1982:16-17).

A factor pertinent to success in a chosen field and related in some way to ability is self-confidence. In psychological attribution theory, self-confidence is generated and reinforced by achieving predictably successful and rewarding outcomes through factors under one's own control, such as effort, rather than through fortuitous events or "luck" (Kaufman and Richardson, 1982:51-53). A number of studies show that young men's and women's self-confidence in both the undergraduate and graduate years, especially in the sciences, is affected in opposite ways. Men's self-confidence is enhanced and women's is diminished even though women's grades, the formal tokens of achievement, remain as high as men's or higher (CEEWISE, 1979:12-13; Feldman, 1974:95-101; Maccoby and Jacklin, 1974:154, 157-158; Zappert and Stansbury, undated:9, 17). These studies, while they demonstrate the effect convincingly, have not traced its causes. Nonetheless, some of their findings suggest strongly that women's loss of self-confidence may be related to differences in the nature and quality of male and female students' contacts with faculty. If so, the effect is likely to depend strongly on the sex of faculty members, and this indeed appears to be the case for both undergraduates (Tidball, 1973:130-135; 1976) and graduate students (Perrucci, 1975:109-110). Some possible relationships with a less satisfactory reward structure for women (less recognition of success, restricted career opportunities) will be explored in the concluding discussion.

Access

The assumption that all students with the requisite ability and interest should have ready access to as much education as they wish is basic to the nation's system of education, although its implementation may be limited by financial constraints and/or by policy considerations that favor some fields over others. This assumption did not fully include women until passage of the Women's Educational Equity Act, also known as Title IX of the 1972 Higher Education Amendments. Until then, women's access to both college and graduate education could legally be restricted, and often was, through various means including outright exclusion, overt and/or covert quotas, and substantial sex differentials in financial aid.

Total exclusion of women from graduate S/E programs as a matter of institutional policy was no longer widespread by the 1960s, although it did persist into that era--e.g., at Princeton. Exclusion of women by departmental fiat or practice was quite common; Harris (1970) provided a comprehensive catalog of methods by which women's participation was restricted or actively discouraged. However, the fact that the major research departments have for some years now educated similar proportions of male and female Ph.D.s argues against the continued existence of restrictive quotas and policies in general, although it in no way disproves their existence in specific cases. A detailed statistical study of possible sex bias in graduate admissions at Berkeley (Bickel, et al., 1975) found that no such generalized bias had existed in 1968-1973 but that some bias favoring women developed at that time. Statistically significant bias against women was shown to have existed in an unidentified humanities department.

The fact that attrition of women between college and graduate degrees varies so widely by field, from essentially none in biological and behavioral sciences to about 25 percent in physical sciences and 57 percent in mathematics, suggests that structural biases may occur in some fields but not in others. Since attrition is in general about evenly divided between graduate school entry and degree completion, some as-yet-undemonstrated factor in graduate admissions to certain departments may play a critical role.

No precise studies exist concerning the effects of women undergraduates' traditionally skewed distributions among institutional categories--i.e., their overrepresentation in public versus private and lower-ranking versus higher-ranking colleges and universities. Although such sex differences have diminished somewhat since 1970 and despite legal mandates to the contrary, most major universities enrolled and graduated smaller numbers of women than men into the 1980s, beginning at a level of about 40 percent in the early 1970s and currently standing at about 47 percent, compared to over 50 percent women baccalaureates nationally. An analysis of the undergraduate origins of science doctorates by Coyle and Syverson (1986:19-21) shows that private institutions, including many with relatively small female enrollments, tend to be much more productive of future Ph.D.s than those public institutions that typically graduate large numbers of women. Some of the female underrepresentation in S/E graduate programs, therefore, is probably the result of skewed undergraduate enrollments.

Short of actual exclusion or quotas, the major factor that affects access to graduate study is financial aid. Providing support for the training of scientists and engineers has long been the cornerstone of all public policy concerned with the continued health of science. The assumption that availability of initial aid and assurance of continuing support will guarantee an adequate supply of highly trained people has been basic to U.S. manpower (sic) planning at least since World War II. The effectiveness of financial support in attracting women to graduate training has not been studied explicitly, but Mooney's (1968) and Patterson and Sells' (1973) findings suggest a strong correlation.

Financial aid for women graduate students in S/E is not well studied; indeed, the topic often has not even been mentioned among the many possible factors that influence graduate participation. In his book-length study of women graduate students, Feldman (1974) devoted one small table and two brief paragraphs to a superficial discussion dealing with adequacy of finances for men and women students in relation to marital status. His lack of attention to the topic is all the more surprising because women students were well known to receive substantially less aid than men (Haven and Horch, 1972) and to come from wealthier families (Harris, 1972:Ch. 1). (The latter observation was traditionally interpreted to mean that poorer families were not much interested in educating daughters, although an obvious alternative interpretation is that only daughters of wealthier parents could afford to study if they received less aid than men.) Feldman stated (1974:136):

> Marital status has very little relationship with the receipt of financial aid. The general pattern is that men are more likely to receive teaching or research assistantships and women are more likely to receive fellowships. Decisions concerning financial aid may take sex into account but probably not marital status. (Underlining added.)

With the possible exception of the final phrase, these statements are borne out by the relatively sparse data available.

Roby (1973:47-50) noted that sex differences in financing graduate study are more complex than for college students. She cited a study by Creager (1971:19), which showed that women Ph.D. candidates received substantially less support than men from teaching assistantships (TAs) and research assistantships (RAs) but more aid from families. Roby noted that these patterns discriminate especially against women from lower-income backgrounds. Astin (1973:144-145) found, using National Research Council data, that for 1950-1960 doctorate cohorts from all fields, only 12 percent of women but 22 percent of men received support from governmental sources while 50 percent of women but only 42 percent of men relied on self-help.

The National Research Council's annual Survey of Doctorate Recipients regularly collects data by sex and field on all sources of financial aid reported by students, but not on dollar amounts. The annual tabulations show a number of sex differences that correspond in general to Feldman's observation. For example, in physical, engineering, and life sciences fields in 1983, about one-quarter more women than men held university fellowships while significantly larger proportions of men held research assistantships (Syverson and Forster, 1983:36).

In 1981 the Survey of Doctorate Recipients focused on financial support issues and analyzed primary sources of graduate support by field, with somewhat surprising results. Methods of financing graduate study vary widely by field as well as by sex, but almost all fields were shown to have more outside support for men while 45 percent of women but only 30 percent of men were primarily self-supporting. (Note that the reduction in these proportions from the data cited by Astin, above, is substantially more favorable for men.) Especially large gender gaps in self-support occur in earth, environmental, and marine sciences (19 percent versus 14 percent), in computer sciences (21 percent versus 14 percent), and in medical sciences (36 percent versus 20 percent), all favoring men. In most science fields the dominant sources of financial aid are TAs and RAs. Women held significantly higher proportions of TAs in earth sciences, math, and computer sciences, but men held much higher proportions of RAs in those fields (Syverson, 1982:15-18). The National Commission on Student Financial Assistance (1983:32, 80) noted that such skewing of aid results in a disadvantage to women, who are more likely to be performing teaching chores for the department and losing corresponding research time while male students are able to utilize more of their time for research, benefiting from greater professional socialization in the process. Clearly, to the extent that more women science students are having to rely on TAs, they are being tracked into the sex-typed occupation of teaching.

The only field group among the natural and mathematical sciences with an egalitarian support pattern--i.e., few if any sex differences in any of the support categories--was biosciences, where only the difference in the proportion of RAs (5 percentage points) remained. Biosciences and psychology, which also has fairly equitable support patterns, are the only major graduate fields in the sciences that have both large proportions of women and a high Ph.D. persistence rate for them. Field, sex, and race differences in graduate support patterns have again been reviewed in the most recent Summary Report on new doctorates (Coyle, 1986:24-28), yielding findings that strongly suggest sex- and race-differentiated practices in the awarding of graduate financial aid.

Overall, access problems for women in S/E graduate studies have clearly diminished since about 1970, when complete or partial exclusion of women from many S/E departments was probably still widely practiced. Since then, most institutions have a stated policy of admitting equal proportions of male and female applicants, which most of them erroneously designate as "sex-blind." If graduate admissions were to be truly sex-neutral and based only on academic performance, the data suggest that higher proportions of women applicants than of men would be admitted.

Questions of equity in financial aid cannot be resolved until a detailed study examines not only field-specific sources and patterns of support, but also possible systematic sex differences in dollar amounts. To the extent that sizable differences in funding patterns exist and that the nature of these differences is such as to impair seriously the quality of some women's educational experience in graduate school, the effect of such practices is plainly deleterious as well as illegal. In its review of women's progress in higher education since 1970, the Russell Sage Task Force notes that financial aid data lead to a curious finding: the fields that require high self-support contributions from all students are also those that have high proportions of women, while the well-supported fields have low female participation, yielding an almost linear inverse relationship. The direction of causality of this phenomenon needs further investigation.

Future studies of sex differences in financial aid should attempt to distinguish between support offered to entering graduate students and continuing support for later stages of study, in an effort to shed light on attrition and persistence issues. In this connection the greater success of women in gaining competitive fellowships, presumably because of superior ability and better credentials, should be examined in some detail. In the normal course of events, reliance on continuing support from a somewhat chancy source is probably less conducive to self-confidence than the more certain income from a research assistantship.

Motivation

The literature on women's achievement motivation in general and on professional career-goal formation is enormous, well beyond the scope of this review, but little of this work is of specific utility in interpreting findings on women graduate students in S/E. Earlier in this review, it was noted that the basic career choice is normally made before entering graduate school but that sustained motivation is necessary for persistence. Support for high aspirations may come from a variety of factors in the personal and educational environment, as well as from a realistic expectation of future professional rewards.

The voluminous literature on women's achievement motivation has been critically analyzed by Kaufman and Richardson (1982) with particular reference to professional achievement. In brief, these authors traced the development of the two major historic approaches to the study of motivation in women: (1) the establishment in children of an intrinsic, stable motive to achieve and (2) the socialization model that stresses the salience of gender-role learning and the incongruence between traditional female gender roles and professional or public achievement. The authors developed a synthesis that argued for a more fluid interpretation of motivation as a response to sometimes changing or evolving opportunities. The latter would certainly accord better with the observed large-scale movement of women into S/E and other nontraditional fields and the very rapid behavioral changes that resulted in tripling the number of women Ph.D.s in a decade.

Feldman's study (1974) of women graduate students illustrates the limitations of both the classic psychological and the sociological approaches to motivation. Examining the stated academic career goals of men and women graduate students (almost 12,000 individuals among the total sample of 33,000 in 1969), he found that about 85 percent of the men and about 70 percent of the women (except for 81 percent in so-called "equalitarian" fields) aspired to teach in colleges or universities; correspondingly more of the women aspired to teach in junior colleges. These sex differences were accentuated in female-majority fields and persisted whether or not a student expected to earn a Ph.D., expressed strong interest in an academic career, or planned to specialize. Women who had a high intellectual self-image and those who attended highly ranked institutions expressed choices much like the men's, but the ambitions of men who rated themselves "not intellectual" or who attended low-ranking institutions were not lowered nearly as much as similar women's. Men in female-majority fields held especially high aspirations, but women did not. Feldman's interpretation of his findings was both superficial and conventional:

> In order for a woman to aspire to a more prestigious career, she must have those qualities associated with that career choice. If she does not, she is much less apt to choose a prestigious career than her male counterpart. . . . Women who aspire toward university careers are more qualified than their male counterparts. Those who are not plan to end up in junior colleges. On the other hand, men opt for university academic careers whatever their qualifications. (1974:79)

He closed that rather extraordinary chapter with the statement that "at the higher-quality institutions, junior college teaching is not a prime objective for students, but these institutions may assume that more women than men will end up in such positions" (1974:101). Feldman did not comment on the self-fulfilling nature of that assumption.

Feldman's data, even for the "female-minority" fields that include most S/E disciplines, are of limited value not only because the conditions they reflect are now largely outdated, but also because the focus on "teaching" in the sense in which he used the term is inappropriate to this field group and because the failure to distinguish between college and university careers is critical. Overall, his conclusions reflect either inability or unwillingness to relate the findings to the reality of academic employment policies in the 1960s, to the graduate students' entirely accurate appraisal of their likely opportunities, and to the realistic gender differences that derived from that appraisal.

In another chapter on dedication to graduate study, Feldman examined a variety of conditions that surely concern motivation, although he seemed not to view them in that light. He found that about one-third of male faculty and fellow students in science fields believed women students to be less dedicated than men (1974:104), although in fact more women report themselves as subordinating other aspects of life to their work (1974:114). More women than men in several science fields said they may drop out because of lack of ability (1974:117), although at least 50 percent more of them had high grades as undergraduates (1974:113). Women science students described themselves as being much less satisfied than men with their ability to do original work, which Feldman interpreted as lack of confidence but which could equally well reflect different situations within departments (1974:118-119) or higher standards of originality being held by women. Women students also were much less likely to have collegial or close working relationships with faculty, and their self-image was accordingly quite low compared to men's (1974:120-121).

These findings on women's apparent underestimation of their ability, their relatively low involvement with faculty, and the consequent low level of self-confidence despite continuing high grades are corroborated by other investigators (Berg and Ferber, 1983:635; Zappert and Stansbury, undated:9). Berg and Ferber found, among a cross-section of graduate students at the University of Illinois, some especially pertinent associations between Ph.D. completion and having been treated as a colleague by faculty, a much less likely event for women than for men. The authors concluded that the motivation of women students could be better supported by improved mentoring by faculty. Zappert and Stansbury examined a sample of Stanford S/E graduate students with respect to sex differences in various measures of professional interest and commitment. A "creativity index" showed some differences: more women felt it essential that a career should allow them to use their skills and knowledge, and more men felt it was important to do seminal work in their fields, to gain social recognition, and to have opportunities for risk-taking.

Certain differences analogous to those reported by Feldman emerged in regard to career plans; 62 percent of men and 51 percent of women expected to hold academic appointments, and fewer women than men envisioned themselves as directors of laboratories, as entrepreneurs, or as corporate chief executive officers. Parallel sex differences occurred in overall satisfaction with their graduate programs, degree of responsibility held within a research group, respect for their ideas accorded them by their advisers, and the general quality of relationships with faculty. One-fifth of the women and 7 percent of the men reported having experienced some discrimination at Stanford. Again, the authors did not attempt to derive any direct relationship between the women's lower expectations, their realistic assessments of opportunity (e.g., as illustrated by the skewed sex distribution of Stanford faculty), and the manifest differences in the graduate experience.

As mentioned earlier, marriage and parenthood, whether existing or anticipated, are widely believed to exercise unfavorable influences on women's graduate study and subsequent careers, usually through making greater demands on women's time than on men's or through constraining women to particular locations. Perhaps because this reasoning seems so obvious, it has not been very thoroughly explored in the few empirical studies that actually deal with women S/E graduate students. Zappert and Stansbury (undated:13) reported that 37 percent of their sample of Stanford medical and S/E graduate students were either married or living with partners, and a total of only 6 percent had children. Among new doctorates in 1985, 58 percent of the men and 48 percent of the women scientists and engineers were married (Coyle, 1986:49, 51). Predictably, about twice as many of the women as the men at Stanford reported experiencing difficulty in integrating family and work demands, and women were significantly more likely to anticipate taking time off for parenting. However, no study has yet attempted to correlate marital status and parenting responsibilities with the more objectively measurable variables that may affect graduate study in these fields. Long overdue are studies that investigate the relationships among such factors as academic achievement (e.g., test scores or GPAs), kind and amount of financial aid, length of time to the Ph.D., marital status including divorce, number of children if any, presence or absence of on-campus child care, and institutional policies that may affect families differently from single people (e.g., whether financial aid is available to both members of a couple).

Discussion and Conclusions

The large and not yet fully exploited data base on doctoral students in science and engineering, as well as other academic disciplines, makes evident the rapid convergence of male and female educational patterns that has taken place since about 1970, when artificial constraints on women's higher education were removed by law. Nevertheless, women remain underrepresented relative to men in most S/E fields while having caught up or surpassed them in behavioral sciences and in some humanities and education fields. This underrepresentation is a growing cause for concern in view of declining interest on the part of men in the traditionally male-dominated areas at a time of heightened awareness of erosion in our international position with respect to both national security and economic competitiveness. The public interest requires actions to remedy these developing problems by the more effective inclusion of women and minorities.

Objective measures of ability and performance make it amply clear that women suffer no deficits in these dimensions and that explanations for lower participation and lower success rates in completing graduate study must be sought elsewhere. Two major areas of interest for further research and possible intervention programs emerge. One of these is the issue of financial support, and the other is the possible effect of improved educational environments (especially with regard to more equitable treatment by faculty) and of equalization of ultimate rewards in recognition, opportunity, and earnings potential on women's initial and continuing participation in S/E fields. The rapid and large-scale increases in women's representation should lay to rest any lingering doubts about native abilities; changes in genetically determined traits do not occur in thousands of people in the space of a decade.

The consistent failure of researchers to explore sex differences in financial aid patterns once their existence had been demonstrated is hard to explain. Such differences are among the potentially most compelling in explaining female attrition from graduate programs at all levels, yet few investigators have pursued the existing leads. Studies seeking to elucidate relationships between funding patterns that track women into lower-level teaching functions and men into preferred faculty careers, or that distinguish on gender lines between those to whom faculty devote full professional attention and those on whom they rely to perform departmental chores, should receive high priority. These issues are complicated by the fact that graduate faculties are not entirely disinterested parties, since they are responsible for the training of those specialists whom they will eventually hire or reject as colleagues. Such a dual role should impose an especially high standard of equity and fairness in the distribution of financial aid, personal attention, and nurturing of high aspirations and in the selection of new colleagues. Massive evidence (see also Zuckerman, this volume) suggests that such a standard has not yet been established or even articulated in most universities.

Finally, the well-documented disadvantages women face in employment after the Ph.D. must be explored with special attention to the deleterious effects they surely exert on the hopes, expectations, and aspirations of women students. An enormous amount of attention has been devoted to what have been regarded as women's intrinsic limitations in entering and pursuing careers in science and engineering. Deficits in mathematical ability, in the personality traits considered essential to successful careers, and in strength of motivation and commitment have all been endlessly examined. In contrast, the entire issue of structural barriers within graduate education in the sciences and engineering has been virtually exempt from investigation for more than a decade. The state of research on women's participation suggests it is time to remedy this omission.

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PERSISTENCE AND CHANGE IN THE CAREERS OF MEN AND WOMEN SCIENTISTS AND ENGINEERS: A REVIEW OF CURRENT RESEARCH

Harriet Zuckerman

Introduction

The National Academy of Sciences elected its first woman member just a half century ago. She was Florence Sabin, an anatomist and embryologist. Not only was Sabin a first here, but her entire career was a succession of "firsts." In 1902, she was the first woman appointed to the faculty of the Johns Hopkins Medical School, arguably the most distinguished school of medicine in the United States at the time. She was also the first woman to be made a full professor there (1917), the first woman elected president of the American Association of Anatomists (1924), and, upon leaving the Hopkins in 1925, the first woman to be made a full member of the Rockefeller Institute of Medical Research (now the Rockefeller University), that being the same year she was elected to the Academy (Breiger, 1980; Rossiter, 1982).

This array of posts makes it clear that Sabin was an insider and member of the scientific establishment. She was also an outsider and social pioneer, being not just the first but often the only woman to be included in the circles in which she moved. (On insiders and outsiders, see Merton, 1972; on social pioneers, see Zuckerman, 1987.) Sabin was atypical, if not unique, among women scientists of the time, in the extent to which her work was recognized and rewarded by the community of scientists. By contrast, the historical record shows that many accomplished women were ignored or actively discouraged. Those honors which came to them at all came very late (Rossiter, 1982).

How much has the lot of women scientists changed since the Sabin era? This review of research on the careers of American men and women scientists will show that this simple question has no simple answer. Rather, as I shall indicate, the pertinent data, drawn from current studies, show three separate but interconnected patterns. First, there are persisting differences between men and women scientists, on average, in role performance and career attainments when viewed cross-sectionally. These differences are almost always in the direction of comparative disadvantage for women and are usually combined with considerable intra-gender differences. Second, there are signs of growing convergence between men and women in access to resources, research performance, and rewards--that is, evidence for increasing gender similarity over the last decade and a half, especially between younger men and women. Third, there is evidence for growing divergence between men and women of the same professional age in published productivity and in some, but not all, aspects of career attainment--that is, for growing intra-cohort differences as members move through their careers.

This report divides into four parts. The first briefly describes the population of American scientists and engineers. The second inventories the main findings of research on comparative career attainments of men and women, earmarking the three patterns of similarity and difference just noted. The third reviews the principal explanations, or "theories," that have been proposed to account for gender differences in careers and assesses how well the data square with these explanations. The last identifies some directions for further inquiry, based on "specified ignorance" (Merton, 1987) or what we now know we need to know and why we want to know it.

Selected Demographic Characteristics of American Men and Women Scientists and Engineers

This review of data on the size, sex composition, and growth rates of the population of American scientists and engineers is not intended to be comprehensive. Instead, it has two purposes: to set in context the more detailed but necessarily more limited findings of research on careers inventoried in the second part of this paper and to provide a cautionary note against the use of simple bivariate distributions of gender and salary, gender and rates of unemployment, or gender and organizational rank in describing the relative status of men and women scientists and engineers. Such bivariate distributions mislead as much as they inform, since they mask marked differences between men and women scientists in professional age, education, and scientific field, these being independently related to salary, unemployment, and rank. These differing distributions of men and women must be taken into account in gauging the extent of gender difference in career attainments. So much then for intent.

Where do things stand with respect to sheer numbers? In 1984, about four million Americans were working as scientists and engineers; and of these, 513,000 (or 13 percent) were women (National Science Foundation, 1986:61; hereafter, NSF)--not a large share but 2.8 times as many as there were a decade earlier, when just 185,000 women (6 percent of the total) were working in these occupations (National Science Board, 1977:152; hereafter, NSB).[1] Indeed, the number of women entering the scientific and technical population has grown even more rapidly than this population as a whole, which almost doubled in the

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[1]Demographic data on scientists and engineers are routinely reported by the National Science Foundation in its report, Women and Minorities; by the National Science Board in its biennial Science Indicators volumes; and by agencies such as the National Research Council and the National Institutes of Health.

same period (NSB, 1977:152). Since the number of scientists and engineers usually grows only by increments of young people beginning their careers (few new entrants are older people moving from other jobs), women scientists and engineers as a group are apt to be younger, on average, than men. This inference is consistent with the report that women are twice as likely as men (60 percent versus 27 percent) to have fewer than 10 years of professional experience (NSF, 1986:4).[2]

Women are also less apt than men to hold advanced degrees, and this is so in every field of science and engineering. In all, 19 percent of men scientists and engineers hold doctorates as against 11 percent of women, but such differences vary considerably from field to field (NSF, 1986:1). Gender differences in educational attainments of men and women suggest that women, on average, may hold high-ranking positions less often than men when the doctorate is a required credential for such high rank.

Even so, the proportion of doctorates being awarded to women has been growing since 1960 and growing particularly rapidly in the last 15 years. By 1985, 24 percent of doctoral degrees in science and engineering went to women as against just 7 percent in 1970 (Vetter and Babco, 1986; see also Vetter, 1981). Such marked increases have occurred against the background of decreases, not just in the relative but also in the absolute numbers of men receiving doctorates (see Figures 1 and 2). It is not clear now whether the prestige of scientific occupations will change as they become more attractive to women and less attractive to men. What is clear is that such high growth rates in the numbers of doctorates earned by women means that women doctorates are considerably younger professionally, on average, than men.

Men and women differ also in the fields they choose, and this is so both for holders of doctorates and for those with lower level degrees.[3] Women are concentrated in the life and social sciences with comparatively small numbers working in the physical sciences and engineering (NSF, 1986:61-62, 71-72) as Figure 3 shows, and this has been so for decades. They comprise just 7 percent of all doctorates in the physical sciences and 2 percent in engineering in contrast to 17 percent of doctorates in the life sciences and 22 percent in the social sciences, these composite fields having once been described as the "dispassionate" and the "compassionate" sciences.[4] (It is not clear whether gender differences also exist in specialty choice.) There are

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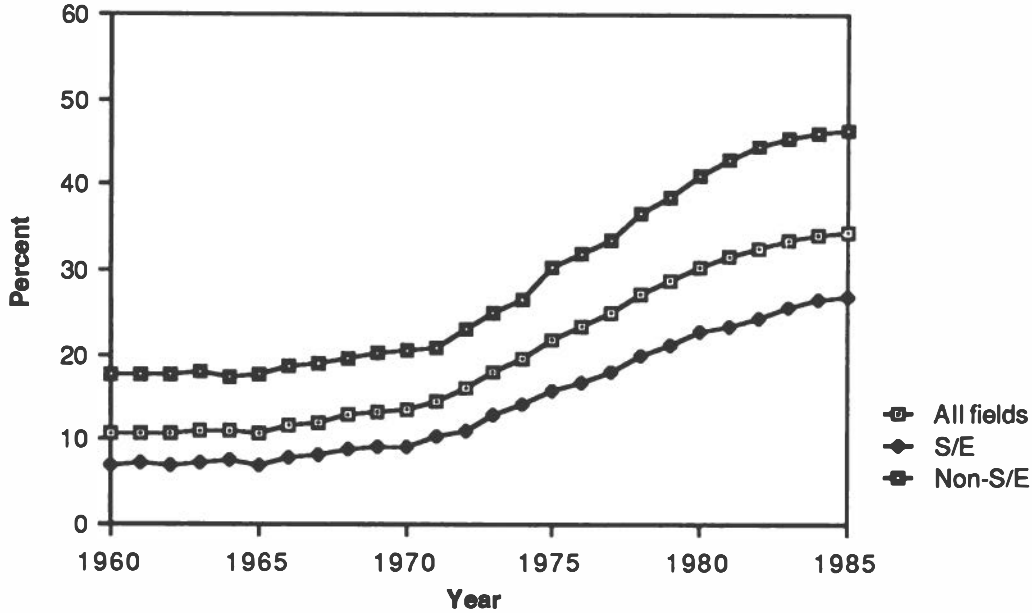
[2]Since I have not located any data on large distributions of men and women scientists and engineers currently at work, I rely on inferences of this sort.

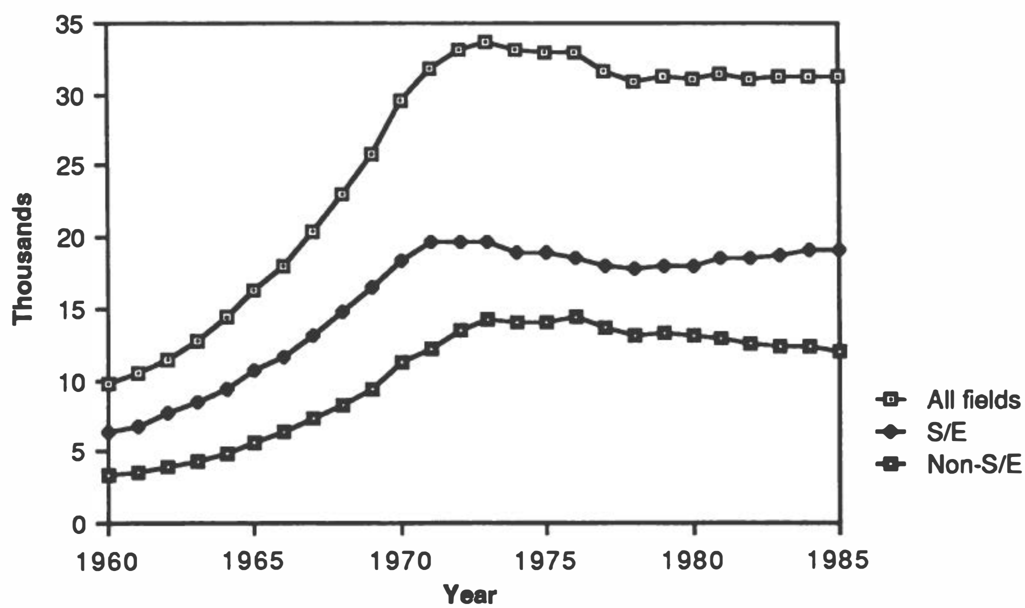
[3]Rossiter (1978) proposes that such differences are responses to the differing job markets in various sciences. Women, she suggests, are more apt to find jobs in new and rapidly growing fields, where shortages make the hiring of women "tolerable." This hypothesis obviously needs careful examination over fairly long periods.

[4]This may be another way of identifying fields with comparatively low and comparatively high loading of mathematical analysis.



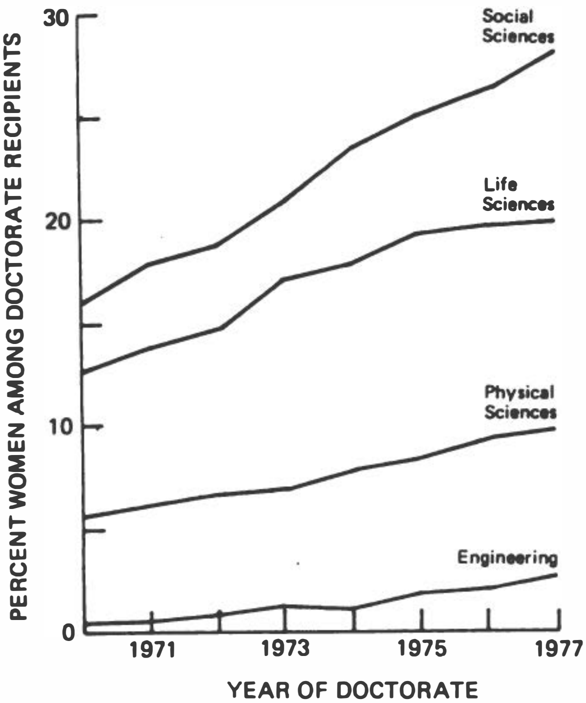
SOURCE: Survey of Earned Doctorates, National Research Council.

Figure 1 Shares of doctorates earned by women.



SOURCE: Survey of Earned Doctorates, National Research Council.

Figure 2 Long-term trends in doctorate production.



SOURCE: Survey of Earned Doctorates, National Research Council.

Figure 3 Percent of doctoral degrees in science and engineering awarded to women, 1970-1977.

marked differences in the representation of women among specialties in psychology (Russo and O'Connell, 1980:31) but no significant differences in specialty choice among men and women in chemistry [National Research Council, Committee on Education and Employment of Women in Science and Engineering, 1979 (hereafter, CEEWISE); Syverson, 1980:24]. In any event, the marked differences that do exist between men and women in the fields they choose must be taken into account in examining salary differentials and differentials in rates of unemployment, since these differ greatly field by field. Recent data show that rates of unemployment are higher and salaries lower in the fields in which women are more numerous, but this has not always been so. Thus, these differences seem not to arise exclusively from the gender composition of these fields.

Men and women scientists and engineers also work in different sectors of the economy. Relatively more men than women (69 percent versus 53 percent) work in industry and relatively more women than men (23 percent versus 10 percent) work in educational institutions (NSB, 1985:Table 3-7). A similar pattern of underrepresentation in industry and overrepresentation in education holds for women doctorates, with some variation by field, but gender differences in sector of employment are not as great among doctorates as among all scientific and technical workers (NSB, 1985:Table 3-8).

While rates of unemployment for scientists and engineers are relatively low compared to those for all American workers, they have been consistently higher for women than for men (e.g., 3.4 percent versus 1.3 percent in 1984) (NSF, 1986:5). For doctorates, rates of unemployment are even lower: 2.5 percent for women and 1.2 percent for men (NSF, 1986:7). While such percentages are comparatively small, they must loom large for those unable to find work. Women are also more apt than men (8 percent versus 2 percent) to be underemployed--that is, involuntarily working part-time or outside science and engineering, a difference that results in part from the small numbers of women in fields, like engineering, which have comparatively good employment prospects for both sexes (NSF, 1986:6-7). Rates of underemployment for Ph.D.s are lower for men and women--1.2 and 2.5 percent, respectively (NSF, 1986:7).

All this means that women's work histories are briefer, on average, than men's and more often marked by part-time work. Since these patterns hold in every field, field differences in employment rates cannot fully account for them. Nor can they be attributed solely to women's domestic and parental responsibilities. Labor force participation rates (that is, the proportions working or seeking work) for men and women scientists and engineers are now high and almost identical (96 percent for men and 94 percent for women). Similar patterns hold for doctorates (NSF, 1986:4; 131ff.). Yet larger proportions of women than men doctorates interrupt their careers for a year or more (17 percent versus 5 percent), and, as Centra (1974:32) shows, spells of unemployment last longer for such women than for men. On average, however, women Ph.D.s remain out of work for a brief time (Astin, 1969: 58). Yet career interruptions do not explain much of the difference in salary paid to men and women scientists (Lewis, 1986). Contrary to widely-held belief, women's work patterns are weakly related to their family obligations; women scientists with young children under six years of age are more apt to be working or seeking work than those with older children (NSF, 1986:5). However women's family obligations are generally assumed to affect their work histories, and these assumptions are socially consequential.

From this brief report, it should be evident, then, that the number of women in science and engineering has risen rapidly in the last 15 years. However, women scientists and engineers work in different fields and in different sectors of employment than men, are younger, and have less professional experience and education. These differences, obscured by simple bivariate distributions, cannot be ignored when comparing the career attainments of men and women scientists and engineers. The sources of gender difference in the choice of fields and sector of employment are not well understood and require more intensive study than they have received.

Research on Career Attainments of Men and Women Scientists and Engineers

Studies of career attainments in science and engineering not surprisingly reflect researchers' distinctive disciplinary interests, styles, and methods of inquiry.[5] These studies are sharply focused:

- On scientists, not engineers--with the notable exception of the research program of LeBold and his group (LeBold, et al., 1983). This limitation is significant, since engineers actually outnumber scientists and comprise 56 percent of all those working in science and engineering posts.
- On academics rather than industrial or government scientists, this also being a significant limitation. Just 12 percent of all scientists and engineers worked in educational institutions in 1983, although a larger share of doctorates (53 percent) did so (NSB, 1985:Tables 3-7 and 3-8).
- On holders of the doctorate rather than those with lower level degrees, the former being just 11 percent of the population of scientists and engineers (ibid.)
- On the current period
- On individual career histories, not the effects of institutionalized processes of evaluation and allocation of resources and rewards on the careers of men and women scientists or their subjective experiences and attitudes.

Thus, the findings of research reviewed here are partial, limited to particular subgroups and to a particular time (see Zuckerman and Cole, 1975, for an earlier review). They are also complicated. To make gender comparisons clear, I take up phases of the career one by one rather than emphasizing their connections in a model. Such models have been proposed (Cole, 1979; Helmreich, et al., 1980; Long, this volume; Reskin, 1978), but longitudinal data for men and women are largely limited to the first 15 years of their careers, making models for the entire career more schematic and speculative than empirically grounded.

Initial Qualifications

The qualifications of men and women beginning careers are now similar in three important respects. First, among doctorates, the only group for which data are available, the intellectual calibre of men and women insofar as it is measured by standardized tests and academic performance is much the same. Women do as well as or better than men on such tests (Cole, 1979:62; CEEWISE, 1979:23-25). However, measured ability seems unrelated to research performance in science (Bayer and Folger, 1966). Second, the proportions of men and women getting degrees from top-ranking research university departments do not differ overall. This is so when departmental rankings are measured by receipt of research funds or by ratings of the quality of doctoral programs (CEEWISE, 1979:37; 1983:2.7). Such differences, however, appear in

[5]These researchers are drawn mainly from sociology, but also from psychology and economics; with a cadre of policy researchers being associated with the Committee on the Education and Employment of Women in Science and Engineering of the National Research Council, researchers in federal agencies have also made important contributions.

some fields: significantly fewer women than men get degrees in top-ranked departments in mathematics and physics, but significantly fewer men than women get degrees from these departments in microbiology and psychology. Given the long term consequences of scientists' doctoral origins for their careers (Long, 1978; Long, et al., 1979), this overall similarity is worth underscoring. Third, men and women are much the same age when they get doctoral degrees. In the doctoral cohort of 1981, the median ages of men and women were 30.3 years and 31 years, respectively, with variation, of course, among fields (CEEWISE, 1983: 2.3). In the mid 1960s, however, new women Ph.D.s were markedly older: the comparable figures were 30.9 years of age for men and 32.5 for women (Harmon, 1978:54). Women also took longer to get their degrees, and a larger share were 40 years old or older when completing their degrees (Harmon, 1978:54-55). By 1981, however, women began careers substantially later than men only in the medical sciences. In all other fields, their ages were approximately the same--that is, within a year of one another (CEEWISE, 1983:2.8).

Thus, women doctorates are quite similar to men in where they got degrees and when and in those attributes that are measured by standardized tests of ability. Men and women are also equally apt (30 percent and 28 percent, respectively, in 1981) to take postdoctoral appointments in the sciences and engineering (Coggeshall, 1981:148), and about the same proportions were accepted for postdoctoral fellowships by top-rated institutions. Such fellowships help to transform recent graduates into independent scientists and provide the opportunity to establish a program of research before teaching begins. The gender similarity here suggests that men and women start their careers as equals in these respects as well.

However, finer-grained data indicate that the gender similarities in postdoctoral appointments are not as great as they seem at first. The reasons that men and women give for taking postdoctoral fellowships differ. Married women particularly emphasize the geographic location of the fellowship more than do single women and men, married or single (Coggeshall, 1981:151). Moreover, Reskin's (1976) study of chemists suggests that women may receive postdoctoral fellowships as often as men, but those they hold have less prestige. This, Reskin conjectures, is indirect evidence that women more often than men accept postdoctoral fellowships because real jobs are unavailable. Further analyses of these same data show that holding a prestigeful fellowship helped men more than women get tenure-track positions after completing their fellowships (Reskin and Hargens, 1979:118). Other studies show that men who had held postdoctoral appointments earned more than women in every field seven years after the fellowship, after taking sector of employment into account (Coggeshall, 1981:156). Such differences in earnings doubtless reflect gender differences in academic and organizational rank and possibly the gender differences in publication that begin to appear at this stage of the career.

Job Histories

What happens to men and women when they search for their first jobs? In engineering, men and women fresh out of college encounter quite similar job opportunities, at least as gauged by salary and by proportions given supervisory and technical responsibility in the year following graduation (LeBold, et al., 1983:22-23). Circumstances are more complex for new college graduates seeking jobs in the sciences. Women now do about as well as men (again using relative salaries as an indicator) in the aggregate, in all fields but the biological sciences (Vetter, 1981:1318); but there is evidence that grade levels and salaries differ greatly for men and women scientists starting work in industry and government (CEEWISE, 1980:4-5). Among new Ph.D.s, gender differences in job opportunities are less marked. This was not always so. The once common pattern of women doctorates having to choose between teaching in a women's college or serving as a research associate in a university laboratory no longer holds. Although women continue to work in academia more often than men, an increasing share of new women doctorates find jobs outside the academy; and similar proportions of men and women doctorates now plan to work in industry (CEEWISE, 1983:2.13).

Confining our attention to academics and to doctorates, current data show, contrary to expectation, that men and women find jobs in much the same kinds of educational institutions. About the same proportions are hired by top-rated universities, whether one uses reputational measures or rankings based on receipt of funds for research. In 1977, for example, about 13 percent of women doctorates employed in academic institutions were affiliated with the top 25 in terms of funding as against 14 percent of men (calculated from CEEWISE, 1979: Table 4.3).[6] These data are consistent with those reported by Cole (1979:70) and by Ahern and Scott (1981:47) for matched samples of men and women doctorates and are significant given the important effects organizational context has on scientists' research performance--although these effects have been demonstrated only for men (Long and McGinnis, 1981).

However, being on the faculty at MIT or Berkeley is quite a different matter from being employed at these same institutions as a research associate or in other off-ladder positions. Too few studies combine data on institutional affiliation with data on organizational rank. Those that do show that women are slightly overrepresented among assistant professors, given their numbers among Ph.D.s generally, with some variation by class of institution. In 1977, 19 percent of assistant professors in the sciences at the top 25 universities were women, 15 percent in the second tier, and 18 percent in other institutions (calculated from CEEWISE, 1979:Table 4.3), this at a time when women earned 12-13 percent of all doctorates in the sciences and engineering. However, a larger proportion of women than men also held instructorships, lectureships, and other off-ladder posts--the outcome, in part but not entirely, of fewer women proportionately holding the

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[6]Moreover, the proportions of women doctorates holding faculty positions at all ranks increased more sharply in the top 50 institutions in the 1970s than in all other institutions (CEEWISE, 1979:76).

doctorate (Bayer and Astin, 1975:797), since the same pattern holds among men and women Ph.D.s (CEEWISE, 1983:4.11).

The same data look altogether different when examined from the perspective of the distributions of men and women Ph.D.s among academic ranks. These cross-sectional data show, of course, that women are heavily concentrated in the lower ranks as compared to men. For example, 37 percent of women scientists and engineers held assistant professorships in 1977 as against 22 percent of men (calculated from CEEWISE, 1979:60, Table 4.3) while the situation was reversed at the top of the academic ladder, where 39 percent of men held full professorships versus 15 percent of women (CEEWISE, 1979:61).[7] Such concentrations are often taken to mean that women are not promoted but are kept in lower ranks. In fact, women do not get promoted to high rank at the same rate as men, but such cross-sectional data cannot show this, since they do not take into account the differing age distributions of the pools from which men and women professors are drawn.

So far then, comparisons confined to new Ph.D.s and to newly hired assistant professors show that women become assistant professors at about the rate that would be expected, given their representation among new degree holders.[8] For this limited group and for the current period, it would appear that gender parity has been achieved, especially at the top-rated institutions. At the same time, it is clear that earlier cohorts of men and women scientists encountered quite different job prospects when they began their careers. Gender parity in the hiring of new Ph.D.s in academia or industry has not, the evidence suggests, been around for long.

Later Jobs

What has happened to earlier age cohorts--to men and women who began their careers a decade or more ago? Cross-sectional data on the ranks that they have attained in educational institutions, industry, and government are less fine-grained than one would like, but they are relentlessly consistent: such women, on average, started out in lower ranks than men, and the disparity in their ranks continues.[9] Available longitudinal data on men and women of the same professional ages do not contradict the cross-sectional evidence. For example, Ahern and Scott (1981:18, Table 2.5) report that among men and women scientists who received Ph.D.s in the 1940s and 1950s and were matched for field,

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[7]In industry, the distributions are similar: 29 percent of men and 16 percent of women work mainly in managerial jobs (CEEWISE, 1983:5.3).
[8]Not all assistant professors are newly minted Ph.D.s, but the great majority are.
[9]Comparable data on scientists and engineers in industry are sketchy but largely consistent with those for academics. The large differences in rank and managerial responsibility for the aggregate of men and women scientists and engineers working in industry suggest that such differences are concentrated among older workers (CEEWISE, 1983:5.3). See Perrucci (1970) for an earlier analysis.

reputation of degree-granting department, and race, 86 percent of men had become full professors by 1979 as against 64 percent of women (a ratio of 1.3:1). In the cohort that got Ph.D.s in the 1960s, a smaller proportion of both men (52 percent) and women (30 percent) had become full professors by 1979, but men proportionately outnumbered women by a ratio of 1.7:1 (calculated from 1981:25, Table 3.5). And finally, among those who had gotten degrees between 1970 and 1974, just 6 percent of men and 3 percent of women had already become full professors. However, 41 percent of the men and 29 percent of the women in this young group, a ratio of 1.4:1, had already been promoted to associate professorships (calculated from 1981:33, Table 4.4). In short, the evidence suggests that men are ranked consistently higher than their age-peers among women.

Gender differences in rank turn up in all classes of academic institutions but are most accentuated in the top-ranking ones (just the opposite of what is observed among assistant professors). On average, the higher the prestige of the institution, the lower the proportion of women in full professorships (CEEWISE, 1979:61; CEEWISE, 1983:4.7) and the smaller the proportion of women assistant professors who are promoted to associate professorships (CEEWISE, 1983:4.13). These differences between institutions need to be treated with some caution, however, since women employed by the higher-ranked institutions may be younger, on average, than those employed in other institutions.

Among those who earned degrees in the 1940s and 1950s, women are disproportionately bunched in what are called "off-ladder appointments"--that is, instructorships and non-faculty posts such as research associateships and other miscellaneous research jobs (Ahern and Scott, 1981:18). Estimates vary on the proportion of women in these posts, ranging from 13-20 percent or about 2-3 times the proportion of men (CEEWISE, 1983:4-15). Such positions are insecure, especially in times when research money is scarce. In many universities, holders of off-ladder appointments have difficulty applying for research funds as principal investigators; they are dependent on others and cannot set their own research programs. Perhaps the only unmitigated virtue of holding such appointments is that they require less frequent attendance at committee meetings than do regular faculty posts.

Finally, trend data on the distribution of women among academic ranks indicate that important changes have occurred. Since the 1970s, there have been increases in the proportions of women scientists in every academic rank in all classes of educational institutions, with the rates of increase being largest in the top-ranked institutions--this being partly the result of so few women being on the faculties of these institutions before the 1970s (CEEWISE, 1983:4.6-4.13). At the same time, it is worth emphasizing that the top-ranked institutions grew very slowly, if at all, in the 1970s and early 1980s. Increasing numbers of women faculty did not simply result from increasing overall faculty size. These trend data, like those examined earlier, show growing similarities in the career attainments, particularly in academic rank, of successive cohorts of men and women scientists. The gap between them is narrowing but it has not been eliminated, especially at the highest ranks.

Tenure

As with rank, so with tenure (the two being strongly intertwined): academic women scientists and engineers are less apt than men to be tenured and also less apt to hold tenure-track jobs (CEEWISE, 1983: 4.15). Among those in tenure-track posts in 1983, two-thirds of men as compared with 40 percent of women were already tenured (NSF, 1986:4). Such marked cross-sectional differences shrink, of course, when professional age is taken into account, but they do not disappear. Among men and women scientists studied by Ahern and Scott (1981) and matched, it will be remembered, for field, doctoral department, race, and age, women in each age cohort were less apt than the matched men to be tenured. Among those who took degrees in the 1940s and 1950s, 98 percent of men and 88 percent of women were tenured by 1979, more of course than among those who took degrees in the 1960s. In this age group, 89 percent of men and 78 percent of women in the sciences had received tenure. Gender differences in rates of tenure are significant in some sciences but not in others. Among younger men and women, the tenure picture is more complex. Among those who received degrees between 1970 and 1974 and were associate professors, women were just as apt as men to be tenured--in all fields, not just in the sciences. But women scientists, it turns out, were less likely than men to have become associate professors (29 percent versus 41 percent) and thus less likely, in the aggregate, to be tenured. Other evidence from large samples of scientists and engineers working in colleges and universities are consistent with these data; the differences in the tenure status of men and women professors appear to be narrowing (CEEWISE, 1983:4.14), suggesting movement toward gender parity in this important aspect of academic careers.

Timing of Promotion and Tenure

For academics, it is not just holding high rank and tenure that matters, but how long it takes to achieve them. Women are promoted more slowly than men; and among those promoted, they are slower to receive tenure. Again, turning to the carefully selected matched samples of men and women studied by Ahern and Scott (1981:27), 24 percent of the women who took degrees in the 1960s and who had tenure by 1979 waited nine years or more to get Ph.D.s as compared to 14 percent of the men (these data are for all fields). Correlatively, younger women doctorates also wait longer for promotion than men. A smaller share of women (44 percent) than men (62 percent) who earned Ph.D.s between 1970 and 1974 and were assistant professors in 1977 had been promoted to associate professorships three years later. However, these data do not tell the whole story. Among those who had already been made associate professors, equal proportions of men and women were promoted to full professorships in this same period (Ahern and Scott, 1981:35). The dominant pattern in all cohorts, however, is that a larger share of men are promoted to high rank than women in the same group and they are also promoted more quickly (CEEWISE, 1983:4.13). Taken together, the greater incidence and more rapid promotion of men enlarge gender differences in attainments among age peers over time. Other data suggest that gender differences in "time to tenure" are more pronounced in top-rated universities than in others--that is, the more prestigious the institution, the longer women wait to be promoted (Ahern and Scott, 1981:40). It is worth reiterating, however, that without data pertinent to role performance of men and women, it is difficult to say much about the causes of gender differences in rank and tenure.

In the case of rank and tenure, the general pattern of growing disparities with age holds up to a point and then narrows toward the end of the career. Large majorities of men and women who remain in academia long enough, do eventually get tenure and most do eventually get promoted. Yet, disparities in rank and tenure persist among older men and women scientists. Among those who have had their doctorates for 30 years or more, as we have already seen, a considerably larger share of men than women hold full professorships, although the vast majority of both are tenured (Ahern and Scott, 1981:18).

Salary Differences

In light of gender differences in rank, it comes as no surprise that women scientists and engineers earn less than men. On average, in 1984, their median salaries were 71 percent as large as those of men (NSF, 1986:7).[10] The disparity varies among fields, is smaller in engineering than in the sciences, and is also somewhat smaller among Ph.D.s than holders of master's and bachelor's degrees. In 1983, for example, women doctorates earned 78 percent as much as men. But since salary is closely tied to age, experience, and rank and since women scientists and engineers, on average, are younger, have fewer years of experience, and hold lower ranks, some differences in salary are to be expected. However, among doctorates in the sciences, "about one-half of the differential in female-male salaries remains unexplained after standardizing for field, race, sector of employment and years of professional experience" (NSF, 1986:8).[11]

In academia, this pattern holds for men and women associate and full professors. Women earn less than men in the same ranks who got degrees in the same years. The most recent data available (1981) show that salary differences between men and women are larger for full than

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[10] The difference is absolutely large, but women in the sciences and engineering in fact generally do somewhat better than women college graduates, who earn 67 percent as much as men with the same educational attainments (NSF, 1986:7).

[11] Again, the data available for industrial scientists are far less detailed than those for academics. These are quickly summarized: women scientists who work in industry have lower median salaries than men, the salary differential increases with years of experience, but (unlike academics) such differences turn up among newly hired men and women as well as among older ones. It is not known whether such differences between men and women are explained by their different field distributions (CEEWISE, 1983:5.5).

for associate professors but absent for men and women assistant professors (CEEWISE, 1983:4.21).

Among full professors, however, women's salaries are not lower than men's across the board; they are as large in some fields--computer sciences, earth sciences, and engineering--but far smaller in others. The largest difference--a median of $6,200 per year (15 percent less than men's salaries)--appears in the medical sciences, and this is followed closely by a difference of $5,800 in economics (14 percent less than men's) (CEEWISE, 1983:4.22). Among associate professors, similar patterns are evident. Women's salaries are comparable to men's in some fields but not in others, with women doing least well in the medical sciences and economics (ibid.). Such differences cannot be attributed to a larger share of women than men working part-time, since these data are limited to full-time employees alone. These data are consistent with those reported by Bayer and Astin (1975), whose detailed analyses reduce salary differences between men and women at the full professor level by holding a variety of variables constant, but do not eliminate them altogether. They report that a residual R of -.12 remains between gender and salary for full professors after the effects of all statistically significant predictors they studied were considered (see also Fox, 1985, on gender differences in salary attributable to rank and function).

Although it is useful to consider rank in comparing the salaries of men and women scientists, doing so makes for systematic underestimates of gender differences in salary. Discrimination against women in promotion and appointments has the second-order effect of discriminating against them in salary, an effect that is erased when comparisons are confined to men and women in the same ranks. Comparisons of the salaries of men and women in any given year also systematically understate long-term gender differences in salary, since these differences accumulate year by year. Even modest median differences in annual salary quickly add up to large differences when considered over the course of scientists' careers.[12]

As with rank, so then with salary. The three patterns noted earlier of persisting gender difference, growing gender parity--particularly among the young--and increasing difference over the course of men's and women's careers hold fairly well. But in the absence of longitudinal data on salary, it is not clear whether the salary gap between men and women narrows toward the end of the career as women catch up to men in rank. However, some hint that this does not occur can be found in the data reported by Ahern and Scott (1981:77). They examined salary residuals for matched triads of men and women faculty who were in the same fields and who had received doctoral degrees at

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[12]As more than one older woman scientist has observed, having earned small salaries and being promoted late has the further consequence of producing small pensions on retirement. Since retirement pay is pegged to the amount of past salary and the number of years that contributions to retirement plans were made, women's annuity incomes tend to be smaller than men's.

the same time. They showed that, on average, women in these triads earned less than the men more often than the reverse was so. Deficits in women's earnings, as compared to those of matched men, increased among older Ph.D.s and were greatest for those in the sample who had the doctoral degree longest (16-21 years). These cross-sectional data on scientists of the same professional ages suggest that disparities in salary may increase with age, but they cannot, of course, substitute for the longitudinal data needed to determine whether the gender disparity in salary actually grows larger with age.

Convergences in rank, tenure, and (to some extent) salary among men and women over the past decade and a half coincide with and may be the outcome of efforts to comply with Affirmative Action legislation. Enacted first in 1972, this legislation made institutions of higher education responsible for correcting gender discrimination in employment, rank, and salary. Such convergences may be consequential for women's later careers. There is good reason to suppose that high rank provides greater resources and opportunities for research, including less teaching, more access to graduate students and postdoctoral fellows, and more space. Thus, recent improvements in rank and the opportunity structure for research for women, possibly associated with Affirmative Action, may enhance women's future research performance while improving their current rewards.

Role Performance

So far, I have focused on gender differences in rank, tenure, and salary and noted repeatedly that such differences need to be examined in light of possible gender differences in the quality of role performance--that is, how effectively men and women do their jobs. Do men and women who do their jobs equally well receive the same rank, tenure, and salary? This question is central because some claim that women are not rewarded at the same level as men because they do not perform as well as men. But while this question is central analytically, it cannot be answered in quite the way it is put. There is no satisfactory aggregate measure of role performance of scientists and engineers considered in their multiple roles as teachers, administrators, researchers, managers, and citizens of the scientific community, even though we do attempt to measure some of these separately. Thus, while we know that this question needs answering, we also know we cannot answer it now.

Research Performance

Some data are available on one significant aspect of scientists' and engineers' role performance: the extent to which they contribute to the advancement of knowledge through publication. The number of papers that scientists publish and the number of times that they are cited--that is, the number of times that their papers are used in the research literature--are, at best, crude measures of research performance. However, many studies show that these are correlated with other, more direct measures of extent of contribution such as peer judgments and honorific awards (Cole and Cole, 1973; Garfield, 1979, 1982; Gaston, 1978; Zuckerman, 1977). These studies suggest, in the aggregate if not in any individual cases, that the extent of publication and citation do register differences in evaluation of contributions to scientific knowledge.

The use of publication and citation counts is by no means uncontroversial (Edge, 1979). And it is important to note that some who find them acceptable for men scientists and engineers object to their use in the special case of assessing the relative research performance of women. These critics claim that few women hold high rank in the top research universities and, thus, few women have as much access as men to the resources needed to do research that leads to high rates of publication and citation (CEEWISE, 1979:xiv). There is merit in this criticism insofar as it emphasizes gender-related inequalities in opportunities to do research and to publish.

At the same time, this criticism is not entirely valid. First, the number of women in high-ranking positions is not too small for comparative analysis and, of course, the number of women in lower-level positions is substantial enough to allow for comparisons with men who are similarly situated. Second, research performance is almost universally taken into account in science in decisions on allocating resources and rewards. Like it or not, research performance is consequential for the careers of men and women scientists, and it is important to know how men and women compare in this respect. Third, it is not only feasible to compare men's and womens' performance (using these admittedly crude indicators), but it is necessary to do so if the sources and consequences of gender differences in research performance are to be identified. And last, should we find that men and women whose research performance is much the same are differently rewarded, this would provide justification for concluding that gender, rather than functionally relevant criteria, really does affect the allocation of resources and rewards--better justification than would be available if such assessments were not made because they were considered unacceptable and even taboo.

With that lengthy preamble, what is known first about the comparative access of men and women scientists to resources for research and then about their research performance? Do men and women have equal access to research support? The evidence here is exceedingly sparse. Limited data on funding at the National Institutes of Health during the early 1970s (NIH, 1981:23-25) show that a small proportion of women apply for research funding, smaller than their numbers in the pool of life scientists. But among those who do apply, women's applications are as apt to be as successful as men's.[13] There are small gender differences in the size of awards that NIH made, but these appear to result from women more often than men applying to programs with small budgets. Access to research funding is crucial to research perfor-

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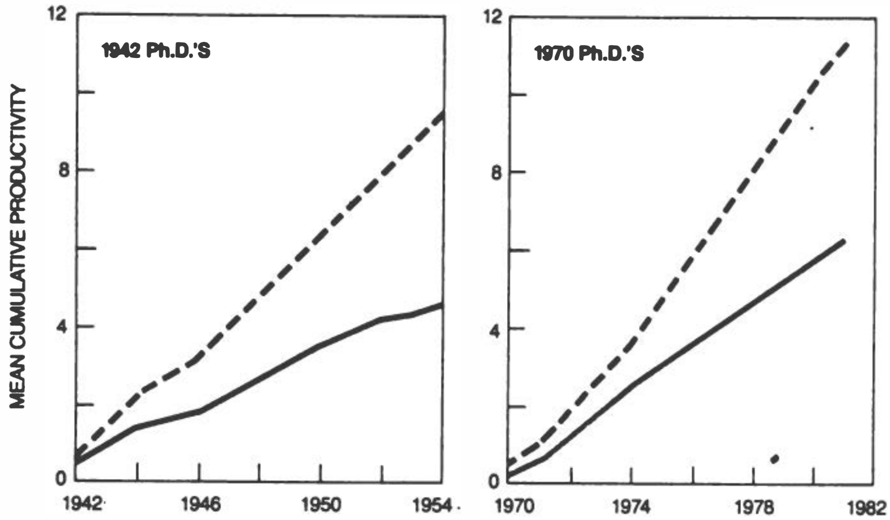
[13]These findings are consistent with those reported for NIH between 1966 and 1972 (Douglass and James, 1973) and for NSF's program in political science (Sigelman and Scioli, 1986).



SOURCE: From J. R. Cole and H. Zuckerman, "Marriage, Motherhood and Research Performance in Science," Scientific American 256(2):119-125. Copyrighted 1987 by Scientific American, Inc. All rights reserved.

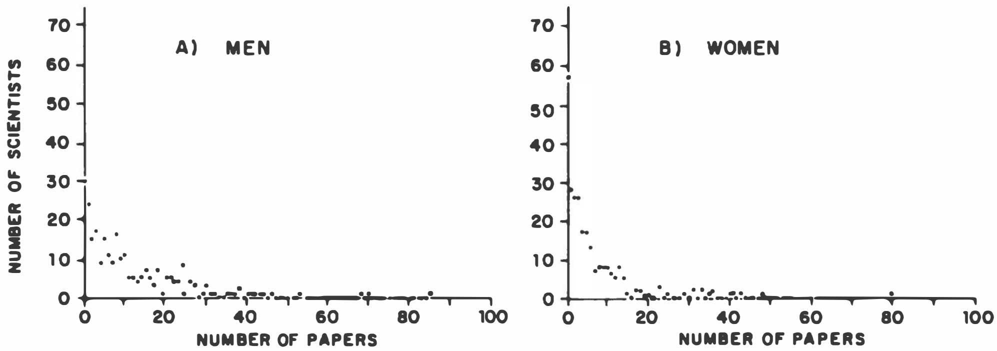
Figure 4 Mean cumulative productivity of men and women scientists who earned Ph.D.s in 1942 and 1970.

mance, and not nearly enough is known about patterns of application for funds by men and women, what success they have, how they fare in the budget-cutting process, and how much money they are ultimately awarded.

When it comes to rates of publication, more than 50 studies of scientists in a variety of scientific disciplines, types of institutions, and different countries show that women publish fewer papers than men of the same ages--on average, 50-60 percent as many (see Cole and Zuckerman, 1984, for a review of the studies since 1975). The weight of the data is persuasive. Moreover, we find that gender differences in publication are smaller earlier in the career than later: data on matched pairs of men and women scientists who received Ph.D.s in the same departments in the same years in the same fields, illustrated in Figure 4, show that gender differentials in publication start early in the career and grow as scientists get older, and this has been so for some time (Cole and Zuckerman, 1984). Such differentials are, of course, reduced considerably when rank and type of institution are held constant, but they are not eliminated.

Detailed analysis of men's and women's publication patterns indicate that the aggregate gender differences are mainly the outcome of differences in the proportions of men and women who publish at a very high rate. As Figure 5 shows, a smaller share of women than men turn up among those who publish large numbers of papers.

However, these data, when juxtaposed with those for earlier age cohorts, suggest that this pattern may be changing. Just 8 percent of



SOURCE: J. R. Cole and H. Zuckerman, "The Productivity Puzzle: Persistence and Change in Patterns of Publication on Men and Women Scientists" in Advances in Motivation and Achievement, P. Maehr and M. W. Steinkamp, eds., Greenwich, Conn.: JAI Press, 1984, pp. 217-256.

Figure 5 Distribution of total publications of men and women scientists who earned Ph.D.s from the same departments and in the same fields, 1968-1979.

women scientists who got their degrees in 1957-1958 published as many as 20 papers in the first dozen years of their careers as against 26 percent of women who got their degrees in 1970-1971 (Cole and Zuckerman, 1984:229). Should these increases continue among still younger cohorts of women scientists, aggregate gender differences in publication will begin to narrow.

Figure 5 also shows considerable intra-gender variation in publication. A great many men publish few papers, and a small fraction publish many. The same is true for women. Moreover, the degree of inequality in rates of publication within each gender is much the same. Gender is, therefore, a poor predictor of published research performance. Knowing whether scientist-authors are men or women will tell little about their rate of publication.

The reasons for gender differences in publication are complex and not well understood. Two comparatively simple explanations--(1) that women co-author papers less often and, therefore, publish less than men, and (2) that women have a harder time than men getting papers accepted for publication--do not square with the evidence in hand. On the first, women are as apt as men to publish co-authored papers (Cole and Zuckerman, 1984). On the second, the evidence usually cited for this claim is a report showing that "blinded refereeing" (that is, removal of author's names from papers) increased the acceptance rate of women's papers submitted for presentation at the meetings of the Modern Language Association (Lefkowitz, 1979:56). It is not clear whether data of this sort from the humanities are quite apropos. Still, a systematic assessment of rates of rejection of papers submitted by men and women is in order under refereeing systems in which authorship is both anonymous and identified. Close attention will have to be paid to match submitted papers not just for substantive significance, but also for other attributes (such as research method and specialty) that might affect the probability of acceptance for publication.

Increasing disparities in rates of publication by men and women as they grow older may indicate that women's access to resources relative to men's diminishes with time and possibly that their commitment to research and publication wanes as they receive fewer rewards and incentives to continue. These are reasonable conjectures that require further inquiry before they can be properly assessed.[14]

Impact or Influence of Research

The extent to which scientists' research is cited in the literature is often used as an indicator of the impact or influence of that research. Just as analysts differ on the usefulness of publication counts in assessing role performance, they also differ on the usefulness of citation counts (see Cole and Cole, 1973; Edge, 1979; Garfield, 1979; Zuckerman, 1987). Recent work by Ferber (1986) suggests that citation counts are particularly biased against women. Her studies show a tendency for men to cite men and women to cite women, at least in economics. Given the small number of women in the pool of citing authors, women's papers receive lower rates of citation. This interesting idea also needs to be followed up in other fields and in specialties with gender-neutral and gender-related subject matters. However, the high frequency of mixed gender author sets in many sciences should reduce the effects of this bias should it occur outside economics. Other data suggest that women's lower rates of citation have quite a different explanation. Analysis of citations to the work of matched men and women in six sciences indicates that gender differences in citation are a function of their differences in rates of publication [Cole and Zuckerman, 1984; Helmreich and Spence (1982) report contrary findings for psychology]. Papers by women authors are cited, on average, just as often as papers by men authors; therefore, aggregate differences between men and women in numbers of publications account for their differences in citation.[15]

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[14]Cole and I (1984) have also suggested that women may respond somewhat differently than men to positive and negative reinforcement of their work (as gauged by citation in the literature). This hypothesis also deserves further examination.

[15]As Long noted (see his paper in this volume), this record of equal citation per paper is surprising given the fact that women, in general, have poorer appointments than men (and thus poorer research facilities) and also less active research programs.

Gender, Research Performance, and Rank

Are differences between men and women in research performance sufficient to explain women's lower ranks and slower rates of promotion? The answer is that they are not. Evidence from carefully analyzed studies by Bayer and Astin (1975) for academics generally, by Reskin (1976; 1978) for chemists, and by Cole (1979) for scientists in five fields show, other things being equal, that men and women with equivalent records of research performance do not hold the same ranks. Men are apt to hold higher ranks than women and this, Cole (1979:57-58) reports, is especially so in the prestigeful research universities. In rank and affiliation, then, comparable men and women do not get equal rewards. And, as I noted earlier, high rank and appointments in universities that facilitate research are, in one sense, rewards, but in another sense, they are resources for further work. To the extent that this is so, these gender differences in rank and affiliation may help account for women's lower aggregate rates of publication later in their careers.

Honor and Repute

How do women fare relative to men in the allocation of recognition for contributions? Again, the evidence on hand is fragmentary. Cole (1979:Chap. 4) has examined the "reputations" of men and women scientists--that is, how visible men and women scientists are to their peers, how their work is assessed, and how often they are named as major contributors to their fields. Women, he finds, are, on average, less visible than men; their work is perceived to be of lower quality; and they are rarely mentioned as being major contributors [see Davis and Astin (in press) for further evidence on reputation--using different measures and having somewhat different results]. Cole also finds that while department, rank, awards, age, and doctoral origins contribute to scientists' reputations, research performance (here the extent of publication and citation) is far and away its strongest correlate. Once research performance is taken into account, being a women does not detract from or add to a scientist's reputation (Cole, 1979:119). However, he also finds that women scientists of the very first rank, Nobel laureates and others of Nobel class, are less well known than men having the same social statuses (Cole, 1979:120). In the absence of further evidence, it is difficult to say why this is so. Moreover, Cole (1979:142) reports that the process by which men and women achieve renown appears to differ, again a finding that is not readily explained with the data in hand but plainly important in understanding gender differences in career attainments.

Scientists are formally honored by an array of prizes and awards. These may seem trivial, but they are not--for recipients, the groups that give them, or the scientific community at large. They reassure honorees that the work they have done matters, they provide incentives for future work, and they call attention to excellence and indirectly help in the intense competition for resources (Zuckerman, 1977).

There are no great differences in the sheer number of awards conferred on men and women scientists; most have received few or none

TABLE 1: Women Who are Members of National Academies of Science and Nobelists in the Sciences (number and percent) and Proportions of Women among Holders of Scientific Doctorates in the Selected Countries

	All Members (N)	Women (N)	Women (%)	Women among Doctorates (%)[d]
Academie des Sciences (1982)	130	3	2.3	19.0 (1970)
Deutsche Akademie der Naturforscher Leopoldina (1982)	1,000[a]	21	2.1	4.8 (1973)
National Academy of Sciences (1986)	1,477[b]	50	3.4	9.8 (1960-1969)
Royal Society of London (1982)	909	29	3.2	9.3 (1968)
Nobel Laureates (1901-1986)	391	8[c]	2.0	[e]

[a]Estimated figure reported by the Akademie.
[b]Excludes foreign associates. Total membership may be slightly smaller owing to delayed reporting of deaths of members.
[c]Madame Curie, laureate in chemistry for 1911 and in physics for 1903, is counted twice. Seven different women have been named Nobel laureates.
[d]Data on proportions of women among holders of doctoral degrees (or in the case of England, holders of "higher diplomas") are given for the years indicated in parenthesis. Those for France, Germany, and England are from the Office of Economic Cooperation and Development, Educational Trends in the 1970s: A Quantitative Analysis, New York: United Nations, 1984, pp. 26-31, and for the United States from Lindsey Harmon, A Century of Doctorates: Data Analysis of Growth and Change, Washington, D.C.: National Academy of Sciences, 1978, pp. 117-119.
[e]There are no reliable estimates of the proportion of women in the pool from which Nobel laureates are drawn.

(Cole, 1979:59). But among those who have, it is difficult to estimate whether women are underrepresented and, if so, by how much. Little is known about the demographic composition of the pools from which award winners of various sorts are drawn. As Table 1 shows, women now comprise 2-3 percent of the members of the major academies and 2 percent of Nobel laureates, the top-most levels of the reward system. We know that academicians and laureates are typically selected from among older, full professors or senior researchers in major research universities and that the number of women in those posts is small. Thus, the extent of underrepresentation of women may be less marked than the last column in Table 1 implies, since the populations of those holding doctoral degrees in the sciences, country by country, include a larger share of young people and particularly of women than the population of potential laureates and academicians. It is not possible to say, then, whether women are now underrepresented in the major national academies and, if so, by how much. In the United States, we do know that the proportion of women elected recently to the Academy parallels their representation on senior faculties (CEEWISE, 1979:102), suggesting that women are now being elected in proportion to their numbers in the pool. However, this conclusion holds only if it is assumed that women are on senior faculties in the appropriate proportions. Some would question whether this is so.

In recent years, however, the number of women elected to the U.S. National Academy of Sciences has risen sharply, by five times since 1972, while the membership as a whole has grown 1.6 times. Moreover, research done some years ago on the ages of members at the time they were elected to the Academy (1865-1969) showed that women were elected nine years later than men in the same fields, yet there was no reason to believe that the research that led to their election was done any later (Zuckerman and Cole, 1975:98). Comparable data for the period since then shows that the average age of women at the time of election has been dropping, though it has not quite reached the averages for men.

On the basis of this limited evidence, it appears that two of the general patterns noted at the outset hold here: cross-sectional differences persist between men and women in reputation with the evidence on awards being scanty but providing some indication of growing gender parity. The absence of longitudinal data on awards that scientists receive over the course of their careers makes it impossible to say whether gender disparities grow as scientists age; but the overall tendency, observed among men, of awards being conferred on those who already have them (Zuckerman, 1977) would seem to suggest this might be so.

Taken together, what does the evidence tell us about career differences of men and women scientists and engineers? As I indicated at the outset, it provides a fragmentary quantitative picture focused mainly on scientists, academics, doctorates, and researchers in the current period. As a consequence, not much is known systematically about the past or about careers of the majority of scientists who work in industry and government or of engineers. What is known suggests that the general patterns noted earlier seem to hold: women scientists and engineers in industry and government occupy lower ranks, advance more slowly, are paid less, and have less managerial responsibility than men (CEEWISE, 1980), but nothing is known about their relative role performance. Among academics, a consistent picture emerges: women scientists' career attainments, for the most part, do not match those of men. In some measure, these differences are attributable to their being younger, having different work histories, and being in different fields than men. We have also seen that they get degrees from equally distinguished institutions, have had postdoctoral fellowships equally often, and now are proportionately represented among assistant professors. Older cohorts of women scientists, however, differ from men in rank, salary, research performance, and reputation, with these differences being almost always in the direction of comparative disadvantage for women. However, there are also signs of growing parity in career attainments, particularly among younger scientists. It is not yet clear whether this trend will ultimately dampen the third pattern, observed earlier, of increasing disparity in men's and women's attainments as they grow older.

Some Explanations Proposed for Gender Differences in Career Attainments

There is little disagreement that women scientists' career attainments, on average, do not equal those of men. There is, however, much disagreement about why this is so. In general, these fall into four classes that emphasize the following:

- Gender differences in scientific ability,
- Gender differences arising from social selection, based on (a) gender discrimination or (b) gender differences in role performance and the allocation of resources and rewards in accord with these differences,
- Gender differences arising from self-selection, including (a) marriage and motherhood and their consequences and (b) gender differences in career commitment, and
- Outcomes of accumulation of advantage and disadvantage.

How well does the available evidence square with each of these explanations? Not well. The evidence on all is ambiguous, not because the theories are unclear but because the data are complex, often vexingly incoherent, and frequently partial.

Gender Differences in Scientific Ability

There is no support, as I noted earlier, for the claim that the different career attainments of men and women scientists result from gender differences in ability or competence. To the extent that these can be measured by intelligence tests or academic performance, women's abilities equal or surpass those of men. However, there is evidence that girls do less well than boys in mathematics and also that girls turn up in disproportionately small numbers among youngsters with high scores on tests of mathematical ability.[16] Benbow and Stanley (1980; 1983) conclude that "superior male mathematical ability, an expression of both endogenous and exogenous variables," accounts for this finding.

[16]See Jane B. Kahle and Marsha L. Matyas, "Equitable Science and Mathematics Education: A Discrepancy Model," included earlier in this volume.

However, there is also enough evidence for marked gender differences in socialization and exposure to mathematics[17] to raise serious questions about this and to warrant further examination of their effects on variability in achievement scores of boys and girls. For our purposes, these findings are not quite entirely pertinent. Men and women who do science are a highly selected sample of all adult men and women. Data on youngsters, even highly selected ones, are not helpful in understanding field and specialty choice, much less differences in adults'career attainments. Yet women do, more often than men, select fields and specialties of science that are comparatively less demanding mathematically, but there is no systematic evidence available indicating why this is so.

Processes of Social Selection

Explanations of gender differences in career attainments that emphasize gender discrimination, on the one hand, and women's poorer research performance, on the other, both rest on notions of social selection. Social selection processes involve decision making about individuals (here, about their careers) over which they have limited control. They contrast with processes of self-selection in which decisions are controlled by individuals and are not, except perhaps indirectly, attributable to socially structured arrangements for selection. In practice, social selection and self-selection are intertwined; but in principle, they are and should be analytically separate. When scientists apply for research support, they engage in self-selection; some apply, some do not. Those who do apply subject themselves to social selection--in this instance, to peer review. It is plainly useful to know whether men and women differ in patterns of self- and social selection and, if so, why. It is not useful to assume that gender differences arise exclusively from one or the other selective process.

Gender discrimination occurs when unequal treatment of men and women is based on the functionally irrelevant criterion of gender rather than on functionally relevant criteria such as role performance. Discrimination can affect men's and women's career attainments when their opportunities for role performance are unequal, when the same quality of role performance is judged according to different standards, and when the same quality of role performance evokes different rewards. Gender discrimination, as with social discrimination generally, treats some social status "as relevant when intrinsically it is functionally irrelevant" (Merton, 1972:20). Proponents of the view that gender discrimination best explains the unequal career attainments of men and women point to instances of women having poorer facilities and resources for research, to their being judged by harsher standards, and to their being promoted and paid less than comparable men.

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[17]See Jane B. Kahle and Marsha L. Matyas, "Equitable Science and Mathematics Education: A Discrepancy Model," included earlier in this volume.

It is no easy matter, however, to assess the extent of gender discrimination and how it affects scientists' careers. Discrimination is often subtle and, therefore, difficult to identify, much less measure. It can be entangled with other forms of particularism (age, for example); and because it appears throughout the career, a full accounting of its effects is hard to make. As a consequence, researchers have come to rely on indirect rather than direct measures of discrimination. They have assumed that differences in the career attainments of men and women that remain after taking <u>all</u> functionally relevant criteria into account (that is, after holding all relevant variables constant) <u>must</u> be the outcome of gender discrimination. Measuring discrimination by the use of residual differences has its problems, not the least that it requires that appropriate evidence be available on all functionally relevant criteria that could account for gender differences in career attainment (on "residualism" in its various guises in the law and in social science research, see Cole, 1979:36ff).

When this mode of analysis is used, the evidence shows that gender discrimination affects promotions, tenure, and salary allocation among academic men and women with similar records of research performance. It also shows that discrimination is receding, especially for younger women. However, available data are limited only to position and to salary and do not register gender discrimination in informal social interaction or its subjective effects on women (see, for example, Briscoe, 1984; Keller, 1977).

There is also evidence suggesting that gender discrimination may operate in different ways for different groups of women. Women who make important contributions to science may fare less well relative to comparable men than do the journeywomen of science relative to their performance peers. Cole's (1979:120) studies show that women who have done important scientific work are less apt to be considered major contributors to their fields than are comparable men. Conversely, it has also been suggested that it is the journeywomen of science who fare poorly compared to men in the absence of any clear-cut evidence of research performance (Zuckerman and Cole, 1975). Thus, the incidence and dynamics of gender discrimination in science have neither been satisfactorily described nor fully explained.

Discrimination need not be reflected only in differences in career outcomes but can also be found in differential processes of status attainment. Reskin (1978) and Reskin and Hargens (1979) suggest that the connections between role performance and rewards for women are less consistent than those that apply in men's careers; women are more often rewarded for poor performance and less often for good performance. And, as noted, Cole (1979) observes that the processes of reputation building differ for men and women. If so, then women do not have as clear incentives for role performance as men and may, as a result, perform less well.

Social selection, as I have indicated, also includes differential evaluation of men's and women's role performance on functionally relevant criteria and differential treatment on this basis. Some believe that women are judged fairly and that gender differences in career attainments result from their performing less well than men. As I have repeatedly noted, we do not know how men and women do in their various roles as teachers, administrators, managers, and citizens of the scientific community. We do know that, on average, women publish less and are cited less than men. To the extent that these actually gauge research performance, then women's poorer performance is related to their lower career attainments, especially in those institutions that put a premium on publication. However, as we have also seen, women's research performance does not explain all such differences; indeed, some remain after research performance and many other variables are taken into account. Moreover, the conclusion that women perform less well than men does not take into account unequal opportunities to do research. The sources of differential role performance may well reside in structured inequalities of opportunity. How much, we do not know.

Gender Differences as Outcomes of Self-Selection

Career attainments are, of course, also shaped by decisions individuals make for themselves, by self-selection as well as by social selection. Women's decisions to marry and to have children, to take on their distinctive domestic and parental roles, are said to interfere with their scientific work and to lead to career decisions that benefit their families but damage their careers. The evidence here is mixed:

- The work histories of women scientists and engineers differ from those of men. They are more often employed part-time or not seeking work and are out of work longer than men. Women attribute these work patterns to their family obligations more often than men. However, actual family obligations (having young children) are a poor predictor of unemployment among women scientists and engineers.[18]
- Married and single women academics are less mobile geographically than men (Marwell, et al., 1979), and married women say that mobility decisions are affected by their family obligations (Coggeshall, 1981; Rosenfeld, 1981). Since promotion and pay increases are often tied to changing jobs, women's limited geographic mobility may, in part, account for gender differences in career attainments.
- Marriage and motherhood are widely believed to account for women scientists' lower rates of publication (e.g., Lester, 1974:42). However, on balance, the evidence suggests that this is not so. Married women Ph.D.s in the sciences publish as much as single women and having successive children is not associated with re-

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[18]Human capital economists emphasize that women's lower educational attainment, intermittent work histories, and part-time employment account in large measure for gender differences in occupational attainments in the work force at large. Indeed, they do account, in part, for the gross cross-sectional differences observed here. They cannot be the whole explanation, however, since gender differences in career attainments hold within groups with the same human capital investments.

duced rates of publication (Astin and Bayer, 1979; Centra, 1974; Cole, 1979; Cole and Zuckerman, 1986; Ferber and Huber, 1979; Hargens, et al., 1978; Helmreich, et al., 1980; Simon, et al., 1966; and Wanner, et al., 1981).

- Moreover, marriage and parenthood are not associated with lower rank and salary among women. In some fields and classes of institutions, the correlations are positive and in others negative. Overall, however, they are not large (Ahern and Scott, 1981:Chap. 6). This is so in spite of the widespread belief that married women have poorer career opportunities than single women.

In short, women's domestic obligations are not the simple explanation of gender differences in career attainments since, in many respects, married women and women with children fare as well or better than single and childless women. However, the diverse career consequences of marriage and parenthood for men and women have not been identified in anything like the needed detail. The judgment on this explanation is still out.

Gender Differences in Career Commitment

There is little or no systematic data on the career commitments of men and women scientists and engineers, especially those holding doctoral degrees. That is, there is no evidence bearing on whether women care less, more, or the same as men about rank, salary, responsibility, and recognition. There is indirect evidence that the preferences of academic men and women differ: for teaching as against research [or at least they did two decades ago (Bayer, 1970)] and for living in urban as against less populous areas (Marwell, et al., 1979). But the connections between such career-related preferences and career commitments are not established, nor are the ways these preferences are shaped by opportunities perceived and real. This hypothesis lacks any support, pro or con.

Accumulation of Advantage and Disadvantage

The notion of the accumulation of advantage and disadvantage has been repeatedly used in studies of stratification in science (Allison and Stewart, 1974; S. Cole, 1970; Cole and Cole, 1973; Hargens, et al., 1980; Long, 1978; Mittermeir and Knorr, 1979; Price, 1976; and Zuckerman, 1970, 1977, 1979). It is plainly pertinent also to the disparity observed in the attainments of men and women scientists. Accumulation of advantage refers to social processes by which certain groups receive greater resources and rewards, such that recipients are enriched at an accelerating rate and, conversely, non-recipients become relatively impoverished [see Merton, (1942) 1973; Zuckerman, 1977:59-60]. When greater resources consistently go to those who can use them effectively--that is, when they are allocated on functionally relevant criteria, the gap in performance that separates recipients from non-recipients grows increasingly large (Zuckerman, 1977:248ff). Advantage also accumulates for certain groups when resources are allocated to them on functionally irrelevant criteria, such as gender. The resulting disparity in achievement between the "haves" and "have nots" is not as great as when functionally relevant criteria are applied, but in both instances the "haves" perform better than the "have-nots" and are rewarded more copiously. The idea of accumulation of advantage helps to account for the observed cross-sectional differences between men and women scientists in research performance, rewards, and recognition, for observed intra-gender variation (since not all women are equally disadvantaged nor are all men equally advantaged), and (not least) for the growing divergence in performance and attainments of men and women scientists as they grow older. It is also consistent with or, more precisely, does not exclude, the third pattern we observed of growing convergence in attainments of men and women, especially among the young.

To the extent that processes of accumulation of advantage and disadvantage are supplemented by self-selection, by women making decisions that benefit their families but have the effect of damaging their careers, disparities between their attainments and those of men will be amplified and accentuated. Although the ideas of accumulation of advantage and disadvantage have been further elaborated and examined empirically not just in science but in other occupations (e.g., Broughton and Mills, 1980; Clark and Corcoran, 1986), detailed evidence is needed on the constituent processes. Although differential access to resources plays a central role in the theory, not much is known directly about how differential access to resources affects performance nor is much known about how rewards are transformed into resources. Before we can conclude that accumulation of advantage and disadvantage and related processes of self-selection really do explain why the career attainments of men and women differ and why these differences increase with time, these gender differences in the allocation of resources and rewards need to be examined.

A Limited Research Agenda: Domains of Specified Ignorance

Finally, a limited number of questions should be earmarked as domains of specified ignorance (Merton, 1987), what we now know that we need to know and why:

1. On the research performance of men and women scientists:
   We need to know why women publish less than men and the extent to which this results from discrimination, differential access to the means of scientific production, and women's preferences or choices. More specifically, we need to know the relative access men and women have to such important research resources as funds, space, appropriate co-workers, and instrumentation. How do women's organizational ranks and institutional affiliations, in combination, affect their resources and their research performance over the course of their careers?

We also need to learn whether there are significant differences in the research strategies and practices used by men and women scientists. Are there greater differences between men and women in these respects than among them? If so, do they affect how much research is done and its impact?

2. On disparities in career attainments of men and women:
Why do these disparities grow as men and women get older? Does the accumulation of advantage explain this pattern fully, or is there evidence also for other explanations such as women's growing discouragement and reduced aspirations? [See Zuckerman and Cole (1975) on the "Triple Penalty" against women, which links discrimination to lowered aspirations.] Longitudinal studies on multiple age cohorts are needed to answer these questions.[19]

   Why do women fare better in certain sciences and less well in others? Is it the case, as Rossiter (1978) suggests, that women do better in new and growing fields? Are the "cultures" of some fields more consistent with feminine values than others, as Keller (1985) and Traweek (1984) imply?

3. On gender discrimination--its incidence, forms, and consequences:
To what extent is discrimination conditional or practiced against all women, regardless of their status characteristics? How does discrimination in its less blatant forms affect women's informal relations with their colleagues and their networks of associations? Rose (1985) observes that the networks of young men and women scientists differ not only in composition but also in how useful they are believed to be. More research attention needs to be paid to the consequences of informal associations for scientists' careers. And, finally, how does the experience of gender discrimination affect women's motivation and career commitment? Do men have equivalent experiences not associated with gender that have similar effects?

4. On changing labor markets:
In what measure are the career attainments of men and women scientists and engineers determined by changing labor market conditions? Is the move toward gender parity likely to be permanent, or will it wane if jobs become scarce?

5. On the career consequences of marriage and parenthood:
To what extent is women's limited geographic mobility (perceived and real) related to their poorer attainments? How do the re-

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[19] It would be useful to have similar studies done on women and men in other professions, since there is reason to believe that gender disparities in the career attainments of lawyers and managers also grow as they age [C. Epstein, 1987 (private communication); Gallese, 1985; White, 1967].

quirements of dual-career couples affect their attainments? This is of no small moment given the fact that a majority of married women scientists are married to men scientists.

6. On commitment to careers:
So little is known about the career commitment of men and women scientists (and other professionals) that this is a thoroughly uncharted domain. It would indeed be useful to know whether men and women differ or are the same with respect to career aspirations, concern with promotion, income, and fame. Believing that they do, some attribute gender differences in career attainments to these attitudinal differences. Others contend that such differences are negligible and that structural barriers faced by women account for differences in career attainments. In either event, this domain of specified ignorance about attitudes requires further examination and needs to be linked to evidence on the behavior of men and women scientists.

So much for the future research agenda. How much have women scientists' careers changed since the Sabin period? They have changed considerably, but it has taken a long time. Sabin's career, then a succession of "firsts," is now far less atypical. It would have been inconceivable in 1925 that women scientists would be hired as faculty members by universities at about the rate they were getting Ph.D.s, and it would have been thought highly unlikely that women would be promoted into senior posts in all classes of universities at the rate they have. At the same time, their career attainments continue, on average, to be more modest than those of men in all sectors--academia, industry, and government--and the gap in attainments grows as men and women age. Moreover, while distinguished women scientists and engineers have become insiders and members of the scientific establishment, some still consider themselves to be outsiders and on the margin. It is not clear at this juncture whether parity will be achieved in the careers of men and women scientists and engineers and, if so, when. It is clear that equal attainments, on average, will require equal access to opportunity for high-level role performance. It will also require the application of functionally relevant criteria first in assessing role performance and then in the allocation of resources and rewards.

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PROBLEMS AND PROSPECTS FOR RESEARCH ON SEX DIFFERENCES IN THE SCIENTIFIC CAREER*

J. Scott Long

Introduction

The literature on the graduate education and careers of women in science is diverse, rich, and complex. Unfortunately, the literature is also fragmented and contradictory, with fundamental questions remaining unanswered. Many of the limitations of this literature can be attributed to a set of common, methodological flaws. If research in this area is to contribute fully to understanding the scientific career, future research must be guided by an understanding of the complexity of the scientific career and the implications of this complexity for the design of research.

To provide a framework for a methodological critique of the literature on women in science, two classes of facts, related to participation and to performance, are suggested and must be explained. Explanations for these facts are then reviewed and critiqued, with a focus on the methodological limitations of past research.

The Facts To Be Explained

The preceding reviews by Hornig and Zuckerman suggest two sets of findings that are fundamental, clearly established, and demanding of explanation. The first set involves the demographics of science; the second set involves gender differences in scientific performance.

Participation in Science

There are two components of participation in science that require explanation. First, being a female decreases one's chances of obtaining a degree in science. Second, if a degree is obtained, being a female decreases the chances of the degree-holder progressing through the "normal" stages of a career, where the normal career may be thought of

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as a typical male career. In short, women are less likely to be scientists, either through failure to obtain degrees or to keep mainline scientific positions.

Arlie Russell Hochschild (1975) quotes figures from the University of California at Berkeley that highlight the demographics of the academic sector:

> Why, at a public university like the University of California at Berkeley in 1972, do women compose 41 percent of the entering freshman, 37 percent of the graduating seniors, 31 percent of the applicants for admission to graduate school, 28 percent of the graduate admissions, 24 percent of the doctoral students, 21 percent of advanced doctoral students, 12 percent of Ph.D.s, 38 percent of instructors, 9 percent of assistant professors, 6 percent of associate professors, and 3 percent of full professors?

These figures give an exaggerated impression of attrition since the increasingly smaller percentages of women found in the higher ranks reflects the smaller percentages of women obtaining Ph.D.s in the past as well as the higher attrition of women. Nonetheless, they vividly portray the fact that being a women decreases one's chances of a successful career in science.

Recent figures suggest that the percentage of degrees in science and engineering that are given to females has increased dramatically. Yet there is little evidence that the differences in attrition between men and women after the receipt of the degree have declined. If this is true, the gains made in granting degrees to females may have substantially less impact on science than they might.

Performance and Recognition

The basic facts regarding the performance of women in science are also clear. First, the performance of women in the coursework and in the standardized examinations leading up to the Ph.D. are, as noted by Hornig, superior to the performance of men. Second, women are less productive than men as indicated by numbers of papers published and citation received. The average female Ph.D. publishes fewer articles and receives fewer citations per year than the average male Ph.D. This finding of lesser productivity must be understood in the context of a third, intriguing, although less well-established dimension of productivity. Namely, the average female scientist receives fewer citations for her work over the course of her career and often finds herself in marginal scientific employment, but individual papers by women receive as many citations as individual papers by men. Research I have recently completed, based on nearly 40,000 articles published by 550 male and 600 female biochemists, indicates that while the average male published approximately 60 percent more articles than the average female, the average publication by a female received approximately 20 percent more citations than the average paper by a male.

Each of these facts is important for understanding the position of women in science. It is a mistake to focus solely on the lesser productivity of women.

The Explanations

Research on gender differences in science must come to an understanding of the processes that generate differential participation and performance. Yet in going beyond the statement of these basic facts, research is, to borrow a phrase from Zuckerman's paper, "vexingly incoherent and frequently partial." The explanations that have been provided are less convincing than the facts that require explanation.

Hornig's and Zuckerman's reviews have suggested five potential sources of gender differences in participation and performance can be isolated: (1) differences in ability; (2) processes of evaluation governed by both universalistic and particularistic criteria; (3) differences in motivation and dedication; (4) role expectations of women with respect to the family; and (5) processes of cumulative advantage and disadvantage. While these explanations are distinguished for purposes of presentation, they should not be viewed in isolation. They operate together, reinforcing one another, and consequently must be understood as a whole. Further, none of these explanations is fully satisfactory. In most cases the evidence is mixed.

Ability

Hornig and Zuckerman point out that there is no evidence that males have more ability than females. Not only are differences between sexes absent in measured ability, but what research there is suggests that variation in such ability does not explain variation in productivity within sexes (Cole and Cole, 1973:67, 68). It is important to note that both reviews were careful to add the qualification that ability is being operationalized as performance on standardized exams and coursework. This suggests that differences in ability may still be a useful explanation of performance if the definition is broadened to go beyond that commodity that allows a person to fill in the correct circles on an examination. This broader definition involves the concept of tacit knowledge.

While graduate education involves the mastery of the technical knowledge that is often measured by standardized exams, there is also an emphasis on the transmission of tacit knowledge. Such knowledge results in a different sort of ability that is essential for scientific success. Michael A. Overington (1977:145) explains tacit knowledge in this way:

> Tacit knowledge--requires an engagement in research on the model of some skillful practitioner in whose person there is incarnated both the general culture of science and particular traditions within the culture. One can no more

> discover the culture of scientific research from its written results than one can construct a Stradivarius from measurements of an original.

Tacit knowledge, by its very nature, is difficult to measure. Nonetheless, that dimension of ability that reflects mastery of the tacit knowledge of a discipline should not be dismissed as an explanation of differences in scientific performance. Given that tacit knowledge is often transmitted through informal contacts, female graduates may be at a disadvantage, in part due to discrimination based on sex.

Discrimination and Evaluation

Differences in performance and participation may result from the evaluation of females by members of the scientific community. To the extent that universalistic characteristics are used in the evaluation, the system is fair and operates as a meritocracy. To the extent that particularistic characteristics are used, discrimination occurs.

Discrimination exists in both blatant and subtle forms. Hornig in this volume describes discrimination in funding during graduate school. Vivian Gornick (1983) documents many cases of a more virulent discrimination by exclusion, where males simply deny females the right to be full-fledged scientists.

In addition to blatant forms of discrimination, it is likely that subtle forms discourage women from active careers and keep them from being as productive as their male counterparts. Subtle forms of discrimination undoubtedly occur in interpersonal relationships. It may occur through disparaging remarks about a woman's ability to have a family and be a scientist. It can occur when females are excluded from "extra-scientific" activities that may result in the transmission of essential, tacit knowledge.

The importance of more subtle forms of discrimination, which may appear to some to be minor inconveniences, is through processes of cumulative advantage, which are discussed below.

While discriminatory evaluations may be the focus of gender differences in science, it is important to keep in mind that differences in advancement and participation can also result from universalistic evaluations. For example, slower advancement in rank may result from the lesser seniority and fewer publications of women. However, such explanations require the answer to the prior question of why women differ in either seniority or publications.

Motivation and Dedication

Differences in motivation are undoubtedly important in explaining the fewer females than males applying to graduate school. Evelyn Fox Keller (1977:130), in her feminist critique of science, has suggested that "perhaps the single most powerful inhibitor [of women entering science] was the widespread belief in the intrinsic masculinity of scientific thought."

Differences in motivation and dedication may also explain differences in performance and career advancement. While Zuckerman reports no strong evidence for this, this possibility requires further consideration within the context of domestic obligations. Further, if a woman drops out of science due to lack of motivation or dedication, it is important to know whether discrimination or demands of family required levels of dedication exceeding those of the most dedicated male.

Domestic Obligations

Differences in motivation and dedication are likely to arise from conflicts between the demands of family and the demands of science. While there is evidence that women are more strongly affected by family and domestic obligations, the consequences of these obligations are unclear in the literature and, I believe, underestimated.

Consider the two seemingly contradictory effects of females' greater family obligations that were reported by Zuckerman. First, family obligations cost women in terms of underemployment and unemployment. Second, marriage and motherhood are <u>not</u> associated with lower levels of publication among female scientists. Married women and women with children publish as much or more, on average, as single and childless women. Further, parenthood is positively correlated with rank and salary for women as well as men.

These conclusions seem contradictory and contrary to much of what we know about the institution of science and the institution of the family. First, science demands a great deal of time. Arlie Hochschild (1975) has made this point with respect to the cost of raising a family:

> The academic career is based on peculiar assumptions about the relationship between work and competing with others, competing and getting credit, getting credit and building a reputation, building a reputation and doing it while young, doing it while young and hoarding time, hoarding time and minimizing family life, minimizing family life and leaving it to your wife. Even if the meritocracy worked perfectly, even if women did not cool themselves out, I suspect there would remain in a system that defines careers this way only a handful of women at the top.

Given that the number of hours a week may be an important factor affecting productivity (Cole and Cole, 1973:71),[1] and to the extent that greater domestic demands are placed on women, it is hard to imagine that this will not adversely affect the scientific careers of women with children.

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[1]However, Hargens, (1975) found support for this relationship in chemistry, but not in mathematics and political science.

Second, family obligations for women are reported to increase underemployment and unemployment, which in turn should adversely affect later participation and performance. In academia, colleagues who take a term in administration or are absent for illness lament the difficulty of reentering research at their prior level of productivity. Women face this difficulty in reentering the career after raising or giving birth to a child. There is little evidence that the university or other employers of women scientists accommodate the interruptions often required by giving birth and raising a child.

In a sense, by not accommodating the biological fact that women give birth, and the consequences of that interruption on the career, there is what might be called cross-institutional discrimination--the demands of the institution of family place women as a group at a disadvantage in the institution of science.[2]

How, then, is the reported result of no effect of family on productivity to be explained? This will be discussed in the section on methodological concerns.

Cumulative Advantage

A line of research generated by Robert Merton's (1968) essay on the Matthew effect has clearly established the importance of cumulative advantage in science. Scientists are experts at pressing their advantages, in reinvesting success to generate greater success. In understanding sex differences in performance, it is important also to consider the converse, the accumulation of disadvantage.

Small differences that result from any of the above explanations can be expanded with time. A short interruption due to the birth of a child may initially be a small disadvantage. To the extent that it accumulates, perhaps as the result of opinions that motherhood and dedication to science are incompatible (even if they are not), the disadvantage may grow, and the career may decline. Subtle forms of discrimination may encourage self-evaluations that define oneself as unlikely to succeed, an evaluation that may be a self-fulfilling prophecy.

The importance of accumulative advantage/disadvantage lies in its ability to amplify other differences, thereby giving other explanations greater effect. This fact is essential for understanding the impact of several of the methodological flaws that are now to be considered.

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[2]In considering the effects of domestic obligations on the productivity and performance of female scientists, it must be kept in mind that female scientists are much less likely to be married than male scientists, and among those who are married, females are less likely to have children. Consequently, the lower levels of productivity and participation by women who are not married must be explained by other factors.

Methodological Problems in Research on the Scientific Career

It is clear from the reviews of the literature that research is fragmented, and all too often contradictory. Studies that might have added critical pieces to an understanding have often resulted in information that cannot be reconciled with past research. To a large extent this can be explained in terms of five methodological flaws: (1) incomplete specifications; (2) aggregation over time; (3) assumptions of uniform effects; (4) sampling on the dependent variable; and (5) inconsistencies in measurement. Many of these errors are easier to point out than to solve. However, if greater attention had been given to avoiding these errors in past research, we would know considerably more than we do about gender differences in science.

Incomplete or Atheoretical Specifications

As the reviews by Hornig and Zuckerman make clear, results are often incompatible or uninformative. In many cases this is the result of incomplete and/or atheoretical specifications of the process being studied. A few examples will suffice:

- It is clear that knowing academic rank without knowing characteristics of institutional location (e.g., prestige) or knowing characteristics of the institutional location without knowing academic rank provides an incomplete picture of a scientist's location in the stratification system. Findings based on either of these variables without controls for the other will be inconclusive.
- Within an institution, as well as across institutions, analyses of the relationship between sex and rank are uninformative without consideration of such variables as seniority and productivity.
- As Hornig notes, any studies of graduate funding that leave out <u>level</u> of funding provide ambiguous and/or incomplete results.

By leaving out key variables that are <u>known</u> to be causally relevant, too many results serve only to describe distributions, rather than explain how those distributions are generated. Too often designs sacrifice detail in the information collected for the size of the sample. Large samples allow one to estimate with great precision the distribution of the variables of interest, but unless all necessary independent variables are included in the study, explanations of the distributions will be impossible to obtain. This is not to say that any given study is critically flawed within the scope of its objectives, but that by making that scope too narrow, designs commonly fail to make the contributions that they might.

Consequences of inadequate specifications are also great when discrimination is assessed by the method of residuals. This method explains differences in performance and achievement in terms of causally relevant variables. The direction of the residuals for one group as opposed to another group are used to assess discrimination. If the prediction is for 10 units and the observed value is 5 units, discrimination is said to have occurred. If the prediction is 5 units, and the observed value is 10 units, unfair advantages are said to have occurred. For example, if males consistently have positive residuals, and females consistently have negative residuals, the conclusion is that females have been discriminated against. The problem with this approach is that it assumes an accurate specification. If one were testing for discrimination in rank promotion without controls for seniority and productivity, the method of residuals would suggest far more discrimination than in fact exists.

Aggregation Over Time

As a particular form of misspecification, excluding time has extremely detrimental effects. While the lesser cost and greater ease of cross-sectional studies are definite advantages, these savings may be obtained at the cost of being able to answer the questions being asked. Consider several examples:

- In a system in which the participation of women is changing rapidly over time, cross-sectional studies cannot isolate the factors explaining differential participation and/or success. The figures quoted by Hochschild for the University of California at Berkeley are quite misleading, since the effects of differential rates of advancement are confounded with time-varying rates of entrance into academia.
- If a cross-sectional study finds that less productive women have less prestigious positions, it is unclear whether the lesser productivity resulted from being forced into a position less conducive to research or whether the lesser position resulted from poor performance.
- Processes of cumulative advantage unfold over time and can only be adequately assessed in longitudinal studies. In cross-sectional studies, a lack of recognition by the scientific community might be explained by a lack of performance. But if that lack of performance is a result of discrimination, which would require a longitudinal design to uncover, an entirely different conclusion would be drawn.

While retrospective designs are an improvement over cross-sectional designs, they are limited in their ability to get at changes in private aspects of the career. That is to say, while it is possible to obtain accurate information on jobs and publications using vitas and published sources, it is questionable whether reliable information about past experiences (e.g., reasons for accepting a particular job) can be obtained retrospectively. Scientists, like other humans, have a wonderful capacity to rationalize the past.

The greatest returns are likely to be obtained from panel designs in which a sample of scientists are followed through time, from entrance into graduate school, through graduate school, and through employment for the rest of their careers.

Assumptions of Uniform Effects

Even in longitudinal designs or in the analysis of data that contain what are considered the most important explanatory variables, biases are introduced by the often implicit assumption that effects are uniform across field, cohort, sector of employment, or sex. Some examples are as follows:

- In some regression models the effect of gender is introduced simply as a dummy variable. In effect, it is assumed that the way in which independent variables affect the dependent variable are identical for males and females. As a consequence, estimates of the effects of independent variables are averaged across sex. Sex-specific effects are masked, and important sex differences may be lost.
- Studies of the effects of doctoral training, fellowships, productivity, and position are limited if analyses do not consider the possibility of the processes operating differentially by sector of employment. Studies that collapse across sector of employment ignore the different demands and expectations for publishing in different sectors. To the extent that males and females enter those sectors at different rates, and such evidence exists, sex differences are masked.

Models must be specified to allow effects to differ across groups, unless there are good reasons supporting the equality of effects across groups.

Sampling on the Dependent Variable

To state that "women who obtain tenured positions in research universities are as successful as men" is not equivalent to stating that "female Ph.D.s are as successful as male Ph.D.s." The first statement is based on a subset of the population of female Ph.D.s that is defined in terms of success, and consequently cannot be generalized to the entire population. Yet too frequently, studies implicitly select the sample on the basis of the value of the dependent variable being studied.

Consider a study of scientific productivity. If the primary research question is to understand what distinguishes a productive scientist from an unproductive scientist, a sample that is representative of all levels of productivity must be studied. If only productive scientists are selected, inferences on factors affecting less productive scientists can only be made if one is willing to assume that factors affecting productive scientists operate in exactly the same fashion as they do for unproductive scientists. And even if such an assumption can be made, severe statistical problems must be addressed. The statistical consequences of sampling on the dependent variable are well known in the literature on sample selection models (Berk, 1983). Inferences from the nonrepresentative sample will not apply to the population of interest.

The apparently contradictory findings on the effects of family may be explained in terms of sampling on the dependent variables. Family obligations can keep women out of full-time positions; at the same time, those who are not kept out of such positions may experience no effect of family on their productivity.

The problem of sampling on the dependent variable is particularly important in comparing male and female scientists, since it is more difficult to collect complete information on females than males. The greater percentages of women who drop out of science, or are underemployed, means that a greater percentage of female scientists will be professionally invisible. Biographical information is less likely to be found in standard sources; addresses are less likely to be found in scientific directories. Further, to the extent that women change their names with marriage or divorce, or change their names back to their maiden names as a consequence of changing social trends, they appear to drop out of science when, in fact only their names have changed. Such women may be lost in drawing a sample. The consequence is a sample that is not representative of all degree recipients but is skewed to more successful or unmarried scientists. To understand gender differences in science, it is not sufficient to understand processes that only affect more successful women scientists.

It is critical that studies be extremely sensitive to their sampling. Samples should be drawn from the population of Ph.D.s that are granted, or, better still, the applicants to graduate programs. While there are reasons for sampling other populations (e.g., scientists at a given institution), but it is critical that generalizations not be made to the entire population of women Ph.D.s and that care is taken to avoid introducing statistical bias.

Problems in Uniform Measurement

Variations in the measurement of research productivity can cause differences in results, and possibly generate spurious findings of sex differences. To take one example, consider the treatment of articles in which a sample member is not the first author. When Science Citation Index is used to collect such data, articles by junior authors are missed. The extent of differences in co-authorship patterns among males and females can result in artificial differences in productivity. Standardization in our measurement of productivity is necessary. Studies are needed to determine the effects of alternative methods of measuring productivity.

Solutions

Solutions depend on dealing with the problems discussed above. The biggest gains can be made by developing a program of research that is based on a multivariate, longitudinal conception of the career.

Here much can be gained by considering the career as a series of events. While this approach has a long tradition, the following discussion will draw on Carr-Hill and Macdonald (1973), who discuss social mobility, and Elder (1978), who considers studies of the family.

Carr-Hill and Macdonald (1973:63) suggest: "It arguably makes more sense to see a life . . . as the outcome of a sequence of events, and to concentrate upon predicting or explaining the probability of occurrence and the nature of those events, than it does to take a life as an additive function of certain background variables plus a stochastic error term." This statement suggests that the scientific career must be viewed as a series of critical events occurring at unique times for each individual. To study the location of individuals in the stratification of science at their tenth year after the Ph.D. is arbitrary and potentially misleading. Rather, the different events that resulted in each individual obtaining the job (that ultimately lead to their location in the tenth year) must be studied. Similarly, to merely compare the productivity of males and females in their tenth postdoctoral year is uninformative without consideration of the events that allocated them to the positions that facilitated or hindered their productivity.

Elder argues for a similar program of "life course analysis" for studies of the family. He writes (1978:21): "The life course refers to pathways through the age-differentiated life span, to social patterns in the time, duration, spacing, and order of events; the time of an event may be as consequential for life experience as whether the event occurs and the degree or type of change." In the life course, timing, not just occurrence of events, is important. He makes the important additional point that the family must be understood in the context of other institutions (1978:22):

> Traditionally, the life course of an individual has been viewed in terms of a single life path, such as the course of a person's worklife or marriage. This approach neglects a central feature of life experience in complex societies--that of multiple, interdependent pathways from birth to death--and is completely inadequate for handling the complex process of marriage and family dynamics.

Conversely, women in science must be understood in the context of the life course--including the family. Too often we operate on the basis of the myth of a unidimensional scientist--who eats, sleeps, and dreams science.

To illustrate how this approach can be applied, consider again the issue of the effect of domestic obligations on the careers of female scientists. Without providing a critique of the individual articles reporting the lack of effect of domestic obligations, and specifically of raising children, on scientific performance, consider how this question might be addressed within the context of a life-course analysis.

For most scientists their careers begin in graduate school. This suggests that the first site for determining the effects of having children on the productivity of a scientist is during graduate education. One might regress the number of publications on the number of children. Given the argument that events unfold over time, definitions of productivity and number of children must be carefully restricted to a specific period of time. Productivity must be measured to include only those publications occurring during graduate school. If it were defined as a summary measure of career productivity, it would include publications occurring after the receipt of the Ph.D. Since later productivity is likely to be the function of events occurring after the Ph.D., it would be inappropriate for the question at hand. Similarly, it is inappropriate to measure number of children as the total number of children at some arbitrary point in the career, as may be done in a cross-sectional survey. It is unlikely that later children affect prior productivity. This suggests counting the number of children at the year of the doctorate. Further reflection suggests that this may be inadequate. The demands of children on parents generally decline over time. While very young children may have major effects on time available for research, older children may not. Consequently, our measure of children should be restricted to the number of young children, say children under six years of age. The resulting analyses would relate the number of young children to doctoral productivity, controlling for characteristics of graduate education (e.g., prestige of the doctoral department, characteristics of the mentor). Further, it is possible that the demands of young children on their parents' time are greater for females than males. Consequently, the analyses must allow differential effects by sex. Preliminary analyses by the author for a sample of biochemists suggest that such steps are necessary to uncover the effects of children on the productivity of their parents.

Conclusions

For progress to occur, studies of gender differences in the scientific career must be unified at the level of common understandings. Research needs to be guided by more careful designs and a fuller consideration of the process being studied. The area of research needs cross-disciplinary panel studies, starting with the receipt of the Ph.D. Not only would this lead to a greater understanding of science, but also of sex differences in science.

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SUMMARY OF OPEN DISCUSSIONS

In the open discussion period, Thomas Hilton asked about the use of minimum SAT scores for college admission when the scores have been shown to correlate weakly with retention and their use seems to discriminate against women. In response, Dr. LeBold said that he personally deplores the exclusive use of test scores for admissions, academic scholarships, and fellowships and views extensive use of test scores as a real barrier to women's participation.

Anna Harrison spoke about rationales for increasing women's participation in science and engineering. One rationale is attainment of equity--equal opportunity for all to participate. Another is attaining parity--50 percent participation as a group. A final rationale is in serving the national need. She noted that at the time she made her decision regarding field of study, 50 years ago, equity was the only issue. She said she was excited by the progress of women during this period in terms of numbers, but even more so because the argument seems now to have moved beyond questions of equity and parity to that of serving the national need. Women must play an active role in the technological society of which all are a part. This, she felt, was the image that children should meet.

Discussion turned to the topic of women and role models. Judith Harris expressed concern about retention of female students in science and engineering: What can be done about the high attrition rate in the first two years of college? Dr. LeBold said that in his studies on retention, women seemed more ready to drop out if their averages were below "B" because they were accustomed to very high grades. Support groups and access to appropriate role models are needed. He said that role models were once all "stars," but now the support groups try to use someone who failed a test once or got a "C" in a course. Elizabeth Tidball said that her research showed repeatedly that sheer numbers of role models were as important a factor as the quality of the role models. She said she would choose to bring in three dozen ordinary women as role models for young women rather than one "star." Marsha Matyas reminded participants that role models do not have to be people who are mid-career and described a seminar conducted by Jane Kahle at Purdue University with women biology majors who were interested in resolving family and career conflicts. In an assignment to work with high school biology students in the laboratory, high school students benefited from the presence of these women, but the biology majors benefited as much from being role models as from other aspects of the seminars. Use of role models not too distant in career levels can thus provide a double benefit.

Robert McGinnis questioned Dr. Zuckerman's statement that there was no relationship between women's marital and parental status and their research productivity. This was contrary to what one would expect. Could Scott Long's suggestion that the research might be skewed by including only working women scientists be an explanation? Had others dropped out because of marital or parental demands? Dr. Zuckerman said that about 20 different publications, reporting data from various sources, consistently found that among working women scientists, married women and women with children were as productive as single women or more so. Her own research on women who had dropped out of scientific careers showed that the demands of marriage and families were a significant factor, but not the only one. She and Dr. Hornig stated that there was essentially no evidence that women with Ph.D.s drop out of the labor force in any significant numbers, and Betty Vetter added that women with Ph.D.s in science do not leave for significant periods when they have children and rarely leave the labor force completely. In fact, men sometimes interrupt their careers for longer periods than women. Alan Fechter cited a recent study by Gwendolyn Lewis concerning career interruptions of men and women Ph.D.s. In response to a question included in the 1982 Survey of Doctorate Recipients, 17 percent of female respondents indicated career interruptions of at least a year compared to 5 percent of male respondents. The effect on earnings--an average drop of 5 percent--was the same for men and women. Dr. Hornig noted that the study had not differentiated between voluntary and involuntary interruptions; research shows that women's career interruptions are more likely to be forced.

Paula Stephan noted that many of the patterns in career differences between men and women in science and engineering have been found by economists in other disciplines as well. Because the patterns, in fact, are fairly generalizable across fields, it would be useful to look at career differentials in that context.

Daryl Chubin commented on possible federal interventions. Could some major legislation at the federal level regarding affirmative action in various kinds of institutions produce effects that would show up in the factors mentioned by Dr. Hornig? Dr. LeBold recognized federal policy aspects to this problem: (1) to become effective, affirmative action should be accelerated, but instead it has decreased; (2) federal programs that were increasing the female pool in science and engineering have been cut from the budget; and (3) there are more federal dollars than ever at the precollege level, but none of the money is dedicated to increasing the pool.

Alan Fechter concluded that there remains a very large gap between the products of research on disparities between males and females in science and engineering and the formulation of proper interventions to correct the disparities. This suggests that a strong evaluation component is needed in the development of models and demonstration programs. There is a tendency to envision the locus of decision making as a single source. There are, in reality, hundreds of decision makers involved and, particularly at the precollege level, unresolved questions about the proper division of responsibility between federal, state, and local governments. Intervention strategies cannot be effectively developed without taking this need structure into account.

APPENDIX A

Workshop on the Underrepresentation and Career Differentials
of Women in Science and Engineering

October 9, 1986

Chair: M. Elizabeth Tidball, Professor
George Washington University Medical School

8:30	Coffee	
9:00	Welcome	Frank Press, National Research Council Mary Clutter, National Science Foundation
9:30	Statistical Overview	Michael F. Crowley, National Science Foundation
9:45	Precollege Education	Marsha Matyas, American Association for the Advancement of Science
10:15	Discussion	Susan Chipman, Office of Naval Research
10:30	Break	
10:45	Undergraduate Education	William LeBold, Purdue University
11:30	Discussion	Susan Chipman, Office of Naval Research
12:00	Lunch	
1:30	Graduate Education	Lilli Hornig, Wellesley College
2:15	Careers	Harriet Zuckerman, Columbia University/ Russell Sage Foundation
3:00	Break	
3:15	Discussion	J. Scott Long, Washington State University
4:00	Adjournment	

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