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ABSTRACT

In response to a request by the Alfred P. Sloan Foundation to examine what attracted women to physics and mathematics, this report has two major goals: (1) to provide a literature review of published studies on women at the college and post college levels in science and mathematics; and (2) to present synopses of three studies carried out at the University of Michigan. The literature review is separated into five topics: (1) statistical trends about women in mathematics and physics; enrollment and graduation trends: decline in interest, and undergraduate programs producing students who earn advanced degrees; (2) enrollment and attrition studies investigating factors influencing women to pursue mathematics and science majors; (3) background characteristics of women in science, mathematics, and engineering; (4) determinants of women's achievement in mathematics and science (individual, environmental, and multiple factors); and (5) interventions employed to recruit and retain women in nontraditional fields of study. The three studies focused on what men and women in mathematics and physics courses believed enhanced and inhibited their decisions to pursue or not to pursue academic work and careers in mathematics and physics. The report ends with recommendations for institutional changes which would have the greatest impact on improving the academic experience of women in the fields of mathematics and physics. (Contains over 300 references.) (MDH)

WOMEN IN MATHEMATICS AND PHYSICS: INHIBITORS AND ENHANCERS

The University of Michigan

March 1992

WOMEN IN MATHEMATICS AND PHYSICS: INHIBITORS AND ENHANCERS

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I. INTRODUCTION

In the Fall of 1989 the Alfred P. Sloan Foundation asked the Mathematics and Physics Departments of the University of Michigan to examine the literature to assess what is known and what strategies had worked in attracting women to these fields. These departments enlisted the help of their social science colleagues on campus and the Center for the Education of Women.

This report has two major goals, to provide a literature review of published studies on women in science and mathematics, and to present synopses of three studies that we carried out at the University of Michigan.

The literature review gives extensive coverage of materials that have been published on women at the college and post-college levels. Far fewer studies have been conducted and published on gender issues at the college than at the pre-college level. We occasionally refer to studies of high school and elementary school children when they amplify a point that seems important for undergraduate or graduate students. The review covers statistical trends; studies of enrollment and attrition and of the background characteristics of women who choose science and mathematics; studies of the individual and environmental factors that influence these choices at the undergraduate and graduate levels; and descriptions of interventions and special programs, including research internships, that have been instituted to attempt to influence the career decisions of women.

The studies conducted at the University of Michigan attempt to fill out what is known about the experiences of women and men in mathematics and science programs at a major research university. We focus on three groups of students: 1) those who took Honors mathematics courses in their first semester at Michigan in the fall terms of 1987 or 1988; 2) those who graduated with degrees in mathematics and physics in 1990; and 3) women currently enrolled in doctoral programs in mathematics and physics. In all three studies we focus on what the students believe enhanced and inhibited their decisions to pursue or not to pursue academic work and careers in mathematics and physics.

These materials lead to recommendations for the design and direction of future research. We end the report with recommendations for institutional changes which our current analysis shows would have the greatest impact on improving the academic experience of women in the fields of mathematics and physics.

II. OVERVIEW

A. Statistical Trends

Proportional Increases for Women

Statistics provided by the National Research Council Survey of Earned Doctorates, the National Science Foundation reports on the state of mathematics, science, and engineering, and the National Center for Educational Statistics make clear that the proportion of degrees conferred on women in these fields has increased over the past twenty years.

Dynamics of the Proportional Growth for Women

The dynamics through which this growth occurred varied over time. Sometimes the proportional increases for women occurred because the drop in enrollments was lower for women than for men. At other times, the number of women enrolled actually increased while the number of men went down. At yet other times, enrollments increased among both genders but more among women than among men. Drawing conclusions about trends based on data from any two to three year period therefore can be quite misleading. To obtain a valid picture of trends, it is necessary to look at the relative enrollments of men and women across a long span of years.

Overall Enrollments

These proportional increases for women must be put in the context of what has been happening to overall enrollments in the sciences and mathematics. Physics and mathematics provide illuminating examples. The absolute numbers of degrees awarded, at all levels, declined drastically after 1970. Compared with 1969-70, in 1980-81 there were only 41% as many mathematics bachelor's degrees awarded and in 1979-80 only 58% as many physics doctorates. In the eighties these percentages have slowly increased to where in 1989 physics awarded 78% as many bachelor's and 78% as many doctorates as in 1970. Mathematics has rebounded much more slowly. In 1989 there were only 67% as many bachelor's and 61% as many doctorates as in 1970.

These figures do not differentiate between citizens and non-citizens. For U.S. citizens, the percentages for doctorates for the latter half of the eighties need to be halved. The absolute numbers of citizens earning a mathematics doctorate (both men and women) have been flat for the latter half of the eighties. In mathematics, in contrast with physics, at the bachelor's level, women are approaching parity in numbers with men. However, many of the women are specializing in actuarial science or teacher education, areas which do not require a doctorate.

The ratio of bachelor's degrees to doctorates is significantly different for physics and mathematics; the physics ratio is 8 to 12 times larger than the mathematics ratio in the two decades since 1970. Probably this reflects the greater job opportunities for bachelor's in mathematics and the use of undergraduate mathematics degrees as preparation for many graduate and professional programs. But this ratio, coupled with the small number of doctorates in mathematics compared with other fields of study and the slow rebound in the number of bachelor's degree recipients, gives definite cause for concern about whether the mathematics community will be able to meet the nation's needs in the 1990s and beyond.

Student Interest

Studies of students' interest in science, mathematics, and engineering do not provide an optimistic picture for the future. A smaller proportion of college students in 1988 than in 1983 intended to major in these fields. This decline in interest raises doubts as to whether or not the upturn in degrees awarded around 1983 will be sustained into the 1990s.

Types of Institutions Producing Male and Female Doctorates

Analyses of the undergraduate institutions that were attended by men and women earning Ph.D.s during the 1980s show that the types of institutions that are effective in producing the nation's doctorates did not differ greatly for men and women. Research Universities I (see Appendix) are the big producers in all fields for both men and women. These large, prestigious research universities are more effective, however, in sending on men than women to mathematics and physics/astronomy. The large comprehensive colleges and universities are the next most likely to produce Ph.D.s, although again in certain fields (e.g., psychology, political science, and foreign languages), these types of institutions are disproportionately effective with men. It is the prestigious liberal arts colleges that stand out for being especially effective with women. In all fields except English, a larger proportion of women than men who earned Ph.D.s in the 1980s had attended the prestigious liberal arts colleges.

B. Enrollment and Attrition: Making the Decision to Pursue Mathematics and Physical Science

Differential High School Preparation: Not the Whole Issue

The high school years are a critical filter that can block or foster advanced study in the sciences and mathematics. Although college women who end up majoring in these fields are better prepared by their high school courses than women who go into other fields, they are less prepared than male students who go into mathematics and science. One of the continuing and serious problems is that female students in high school still elect fewer mathematics and science courses than male students.

Lack of preparation is not the whole story, however. There are enough young women who are sufficiently prepared by high school background to achieve parity with men as science majors as has occurred in mathematics. At the University of Michigan in the fall of 1989, 76 percent of the females and 90 percent of the males entered with four years of high school mathematics. This yields a sizeable group of female students who could potentially go into mathematics and the sciences. Moreover, in the studies of Michigan undergraduates included in this report, academic ability and preparation did not differ substantially by gender.

The Decision Process

Women who enter college with a commitment to some type of science are more likely than their male counterparts to choose either biology or medicine. In our study of students taking first year Honors mathematics, women were more than twice as likely to go into medicine as into mathematics or pure sciences, while men were three times as likely to choose mathematics or sciences as medicine.

These intentions are not set in stone, however. Studies of men's and women's decision processes indicate that women tend to make the decision to pursue science careers later than men, so there is still an opportunity to attract women into science in the early college years. In our study of mathematics and physics majors, nearly half of the women had not entered college intending to go into these fields. Our studies show, moreover, that experiences in initial college courses often influence the choice of major.

C. Determinants of the Science/Mathematics Choice

Personal Determinants

The research on individual factors assumes that barriers to women's achievement in mathematics and the sciences lie within the individual. Sometimes it is argued that women lack mathematics ability or spatial visualization, although other researchers put less emphasis on ability than on motivational factors such as self-confidence, attitude and interest among women.

Ability: Studies of the abilities of males and females to perform certain specific mathematical tasks (problem solving, spatial visualization, computation) do not show a conclusive picture of gender differences. There is growing agreement in the research literature that what differences do exist are already quite small. Furthermore, these apparent task-related gender differences can often be explained by differences in preparation.

Self-confidence: Differences in self-confidence may account for why more men than women go into the sciences and mathematics. Self-confidence may well be the most distinguishing characteristic in the approach of men and women to mathematics. It is important to note that women report lower confidence even when they perform as well as males, and that their confidence drops during the critical early years in college. The situations which erode confidence are those in which social comparisons are made publicly, those in which performance feedback is somewhat ambiguous, and those in which the task is societally defined as typically male. Women who succeed in mathematics and physics show a high degree of self-confidence, but the causal dynamics of this relationship are not yet understood.

Other Factors: Research shows little evidence of other motivational differences that conceivably might account for the gender patterns in mathematics and science. Studies of specific attitudes and preferences find only small and often no gender differences. New research on the role of emotion in problem solving and the learning of mathematics has not yet probed the impact of gender. Finally, while there do seem to be some reliable gender differences in relevant personality traits and in causal attributions, these differences are not large enough to account for the clear edge that males have in choice, retention, and achievement in mathematics and science.

Gender Stereotypes

Self-confidence and sex-role congruency are intertwined in their effects. Women students do not easily venture into a sex-role inappropriate realm and must have unusually strong confidence in their abilities to counter societal definitions of appropriate gender roles. The gender stereotypes which depict mathematics and science as male endeavors continue to affect women's choices of majors and careers.

Environmental Influences

We have already noted that initial college courses and overall college experiences influence women's choice of majors. In general, the research on environmental factors shows that women are especially sensitive to cues from the environment that tell how well or how poorly they are performing and how likely or unlikely it is that they will succeed. Women's socialization trains them to be more sensitive than men to negative experiences of the environment, as well as more sensitive to supportive ones.

Many studies of environmental factors have focused on classroom dynamics and in particular on possible differences in the interactions between teachers and their male and female students, differences in the responses of male and female students to teaching style, differences in responses to competition between students and to classroom climate, and differences in the social support given to male and female students.

Encouragement: Direct encouragement, getting information about opportunities, being taken seriously by teachers and counselors, and having a comfortable relationship with an advisor are all important to both men and women. But according to the published literature and our own studies, women students report receiving fewer of these positive experiences. In our studies of majors in mathematics and physics and of students who took Honors mathematics, we found that the female students had received less encouragement and less information about accelerated course work than had the male students. Our focus groups with current graduate students in these fields confirm that encouragement from faculty members, parents, and peers during the undergraduate years was critical in bringing about their eventual commitment to pursue advanced degrees.

The effectiveness of the prestigious liberal arts colleges in sending women on to doctoral work may stem from the amount of encouragement and feedback which can occur more naturally in a small department.

Research Internships: Research internships help both men and women students. These experiences are especially useful for students who are uncertain of their career paths. Students are more likely to continue in mathematics and science fields if they have opportunities to work in science laboratories and other research settings. For women, the close interaction with a faculty member plays an important role in building self-confidence.

Gender-Biased Classroom Experiences: There is some evidence that women majoring in mathematics and science have more negative classroom experiences than women in other fields. The women report feeling put down, being called upon less frequently, patronized, and ignored. Both men and women mathematics and physics majors agreed that the gender of a student has an effect on how the student is treated, and the women students were nearly unanimous in the view that it is women who are treated less positively. There are, however, some teachers who are particularly successful in encouraging women to go on in science and mathematics. These teachers include information on women scientists in the curriculum, avoid sex-stereotyped views of science and scientists, and are sensitive to not using sexist language.

Mathematics as Problem Solving: The research literature provides some evidence that men and women students approach the study of mathematics somewhat differently. Women more than men tend to perceive mathematics as something done according to rules and may be less likely to seek alternative approaches to a problem. A less algorithmic approach to calculus would probably have a significant impact on attracting and retaining women students, as would a problem solving course requirement. Preliminary results from a University of Michigan freshman combinatorics class and a new innovative chemistry course indicate that women may flourish in discovery-based classes.

Competitive Environments: Women generally respond negatively to what is perceived as an overly competitive environment. The general literature we have reviewed and our own study of Honors mathematics students indicate that women find cooperative atmospheres somewhat more helpful and competitive atmospheres more harmful than do male students. The research on competition, however, has not distinguished between various types of competition or exactly why an environment is perceived as competitive. Most often the studies simply present the terms, "competition" and "cooperation," and let students provide their own definitions. The studies look at practices such as grading on a curve, ability grouping, individual and team competitions for prizes, and excessive emphasis on grades. Since these practices inevitably involve individual social comparisons, they have a negative effect on the confidence of women students. More research needs to be done to find out exactly why competitive environments seem to deter women more in science and mathematics than in other fields, and to delineate which competitive practices have the most negative impact.

D. Description of Current Intervention Programs

Many colleges have designed programs to increase the numbers of women who complete degrees in mathematics and the physical sciences. Most of these programs can be grouped under the following headings:

1. Recruitment and attempts to stimulate women's interest in the career.
2. Support (e.g. mentoring, networking, peer groups).
3. Internships and apprenticeships.
4. Re-designing courses and degree programs.

Very few programs have been developed to change the institutions themselves by restructuring the academic environment or by changing the attitudes and behavior of faculty members.

University of Michigan Studies

If the pool of U.S. mathematicians and physicists is to be enlarged, research universities must play a central role. Yet few studies have examined the experience of mathematics and physics undergraduate and graduate students in major research universities.

In order to address this knowledge gap, during the past year three studies were conducted at the University of Michigan under the auspices of the Sloan Project. Each of these studies explored students' perceptions and the factors which contributed to student persistence or attrition.

The first of the three studies surveyed students who were enrolled in first semester Honors mathematics courses during the Fall Terms of 1987 or 1988. The study documents a high "dropout" rate in terms of continuing mathematics enrollments. Gender differences revealed by the study appear to be based on differences in perception, not in ability.

The second study examined the experiences of students who graduated with majors in mathematics and physics in 1990. While this study revealed few gender differences, the differences which did emerge were consistent with those identified in the study of Honors mathematics enrollees and in the larger body of research literature. Even among those who completed mathematics and physics majors, women were less likely to find encouragement in their departments, less likely to find professors to take a special interest in them, and had slightly lower self-confidence than their male counterparts.

The third study involved two focus groups of women graduate students in mathematics and physics. Several themes emerged from the qualitative analysis of the focus group content that were again consistent with the literature and the data from the two Michigan surveys. For example, encouragement from faculty and parents played a key role in the women's undergraduate experience and their decision to persist in their studies.

Summary and Evaluation of Past Research

Summary of Research Results

The existing research reveals significant gender differences in the areas of self-confidence, amount of interaction with faculty, level of faculty expectations and encouragement, response to competitive situations, response to poor and alienating teaching, and relative chilliness of the scientific climate as a result of gender bias and stereotyping.

There are also small differences between male and female students on measures of problem-solving ability, personality traits of independence and creativity, and attribution patterns.

Research Design Limitations

Our review of the research literature reveals five major limitations that should be addressed in future studies.

First, the majority of studies of both personal and environmental determinants of students' choices and achievement in mathematics and science focus on the elementary and secondary level. Much less research has been done at the college level, and virtually no systematic research is being carried out on graduate students.

Second, intervention programs have not been accompanied by any long-term studies of effect. Very few programs use random assignment so that effect could be reliably assessed. And the intervention programs do not appear designed to address the issues raised by the research.

Third, since much of the research has been carried out in single institutions, there is a need for a national study of students enrolled in a representative sample of different types of institutions.

Fourth, although career choice occurs across time, the research literature on choice of mathematics and science depends almost entirely on cross-sectional rather than longitudinal studies.

Fifth, given the importance of environmental factors, there is a critical need for carefully designed observational studies in which the impact of classroom dynamics and the academic climate can be studied in depth.

Recommendations

Our review of the material and our own research studies suggest the need for both new designs and new directions for future research. However, we do not need the results of additional research to recognize the many forces which erode women's confidence and undermine their abilities. Our analysis points to the need for intervention programs aimed at orienting women towards graduate school and mathematics and science careers. We also recommend a set of goals and strategies to bring about change within the institutional structure of departments, colleges and universities. The academic experience of women will be improved by programs which strengthen the communication between students and faculty; programs which increase the numbers of women students and faculty; and programs which provide an academic atmosphere in which women are expected to succeed and in which sufficient numbers of successful women are visible at all levels.

III. LITERATURE REVIEW

A. Statistical Trends

Women now enter both undergraduate and graduate degree programs in engineering and computer sciences in much larger numbers than they did twenty years ago. The proportion of degrees conferred on women in both of these fields has increased as well. In mathematics and physics, however, the absolute number of women earning degrees is down at all levels; but since the number of men has gone down relatively more, the proportion of degrees awarded women has increased. These trends are now well documented. (See Jagacinski and LeBold, 1981; Vetter, 1981, 1988.)

The field of engineering illustrates the shift that has taken place for women. (See LeBold and LeBold, 1987, for a detailed discussion of the statistics presented here.) During the period 1971-1985, the percentage of women students enrolled in engineering programs rose from 2.6 percent to 16.5 percent. Likewise, the percentage of Bachelor of Science degrees awarded to women in engineering during this period rose from .8 percent to 14.7 percent. Corresponding increases occurred in engineering fields for the awarding of both master's degrees (from 1.0 to 10.2 percent) and Ph.D.s (from .7 to 5.7 percent).

Similar gains for women have taken place since 1971 in the field of computer science. In 1971, women earned 14.5 percent of the baccalaureates in the field of computer science. These percentages had more than doubled by 1980, with 30.3 percent of the degrees going to women (Vetter, 1981).

Statistics for Mathematics and Physics

The picture is also one of relative growth for women in mathematics and physics. In both fields, a larger proportion of degrees at all levels is now conferred on women than in 1970. Throughout the past twenty years, the absolute numbers of women earning degrees (and the proportion of degrees given to women) has always been greater in mathematics than in physics.

In mathematics, the proportion of degrees earned by women increased between 1970 and 1989 from 37 to 46 percent at the bachelor's level, from 30 to 40 percent at the master's level, and from 8 to 18 percent at the Ph.D. level. The dynamics behind these increases are similar at all levels. In general, the percentage increase in degrees awarded to women has resulted from two change processes. Earlier in this period the percentage increase occurred because the drop in the number of women getting degrees in mathematics was relatively lower than the drop among men. Then, when the number of students going into mathematics began to increase in the mid-1980s, there was also an increase in the proportion of degrees conferred on women. This was because the numbers of women earning mathematics degrees increased relatively more than the numbers of men. (See Tables 1 and 2.)

In physics, the percentage gain that women achieved over most of the past twenty years has also resulted from gender differences in relative decreases and increases in numbers of degrees awarded. Earlier in this period the proportional increase for women occurred because the drop in the number of women getting degrees in physics was relatively lower than the drop among men. And later the increased number of degrees awarded to both men and women was proportionately greater for women. The proportion of degrees given to women increased between 1970 to 1989 from 6 to 15 percent at the bachelor's level, from 7 to 17 percent at the master's level, and from 2 to 9 percent at the Ph.D. level. (See Tables 3 and 4.)

Enrollment and Graduation Trends

First, the increases in the proportion of degrees earned by women since 1970 must be put in the context of what was happening to overall enrollments in these two fields. The absolute numbers of degrees awarded, at all levels, declined drastically after 1970. Compared with 1969-70, in 1980-81 there were only 41% as many mathematics bachelor's degrees awarded and in 1979-80 only 58% as many physics doctorates. In the eighties these percentages have slowly increased to where in 1989 physics awarded 78% as many bachelor's and 78% as many doctorates as in 1970. Mathematics has rebounded much more slowly. In 1989 there were only 67% as many bachelor's and 61% as many doctorates as in 1970.

Second, the dynamics through which the proportional increases for women occurred varied over time. Sometimes the proportional increases for women took place because the drop in enrollments was lower for women than for men. At other times, the number of women enrolled actually increased while the number of men went down. At yet other times, enrollments increased among both genders but more among women than men. Drawing conclusions about trends based on data from any two- to three-year period therefore can be quite misleading.

Third, since these figures do not differentiate between citizens and non-citizens, the importance of drawing more students, and especially women and other underrepresented groups, into mathematics and science is perhaps not as dramatically presented as it should be. For U.S. citizens, percentages for the doctorates for the latter half of the eighties need to be halved. The absolute numbers of citizens earning a mathematics doctorate (both men and women) have been flat for the latter half of the eighties. In mathematics, in contrast with physics, at the bachelor's level, women are approaching par in numbers with men. This suggests that growth in the number of mathematics doctorates will need to come from both men and women and perhaps especially from women (see Figure 1).

Fourth, the ratio of bachelor's degrees to doctorates is significantly different for physics and mathematics: the physics ratio is 8 to 12 times larger than the mathematics ratio in the two decades since 1970. Probably this reflects, in part, the greater job opportunities for bachelor's in mathematics. But this ratio, coupled with the small number of doctorates in mathematics compared with other fields of study and the slow rebound in the number of degree recipients, gives definite cause for concern as to whether the mathematics community will be able to meet the nation's needs in the nineties.

Decline in Interest

A declining interest in the sciences and engineering has been reported for both males and females. In 1988, roughly 23 percent of college women intended to major in a science field, whereas 27 percent had that intention in 1983. The decline in interest (30 v. 21 percent) was even greater for college men. The field of computer science has witnessed some of the most dramatic declines. In 1988, only 2 percent of college women planned to go into this field, compared to 9 percent in 1983. The comparable percentages for men were 4 percent in 1988 and 12 percent in 1983. (Task Force on Women, 1989.) This picture of declining interest raises doubts as to whether or not the upturn in degrees awarded in mathematics and physics around 1983 will be sustained when degree figures are available for the early 1990s.

Undergraduate Programs Producing Students Who Earn Advanced Degrees

The National Research Council has collected data on the types of institutions that men and women earning Ph.D.s in the 1980s had attended as undergraduates. Most of the doctorates were earned by students who had attended eight types of institutions, as classified by the Carnegie Code: Research Universities I, Research Universities II, Doctorate Granting Universities I, Doctorate Granting Universities II, Comprehensive Universities and Colleges I, Comprehensive Universities and Colleges II, Liberal Arts Colleges I, and Liberal Arts Colleges II. (See Appendix A for the description of the Carnegie Codes defining these eight types.)

Figures 2a - 2j show the proportions of doctorates earned by men and women in four natural science fields, three social science fields, and two humanities fields in relation to the types of undergraduate colleges and universities attended.

Overall, research universities accounted for the largest proportions of doctorates earned by both genders in all fields. Some differences by field are notable, however. Students who earned doctorates in mathematics, physics, and biology were the most likely to have attended these large, research universities, while those who earned doctorates in chemistry and English were somewhat less likely to have done so. These differences by field exist among both men and women. To some extent, type of institution is a factor in the doctorates earned by men and women. Mathematics and physics show a remarkably similar gender pattern. A larger proportion of men than women who earned doctorates in these fields had attended Research Universities I, and a smaller proportion of men than women had attended Comprehensive Universities and Colleges, as well as Liberal Arts Colleges I. These differences range between 7 and 12 percent.

These overall generalizations do not capture an interesting phenomenon that is revealed by analyzing which institutions produced as many as five women earning degrees in physics/astronomy and in mathematics in this decade. In this analysis, liberal arts colleges are shown to be much more prominent in educating the women earning degrees in physics/astronomy than in mathematics. Eleven of the 31 institutions that produced as many as five women who subsequently earned Ph.D.s in physics/astronomy were prestigious liberal arts colleges. They include fairly equal numbers of women's and co-educational colleges. (The women's colleges are Wellesley, Mount Holyoke, Bryn Mawr, Smith, Radcliffe, and Barnard; the co-educational colleges are Dartmouth, Swarthmore, Carleton, Oberlin, and Harvey-Mudd.) The list of institutions producing as many as five women who subsequently earned Ph.D.s in mathematics is quite different. Only three of the 41 institutions that managed to send on that many women to mathematics higher degrees were liberal arts colleges, and all were women's colleges (Smith, Vassar, and Bryn Mawr).

The aggregate figures represented in graphs (Figures 2a - 2j) show some commonalities across certain fields. A common pattern with respect to gender can be seen in chemistry and biology. In both of these fields, across several types of institutions, there are minor gender differences all of which favor men. These differences are largely compensated by the prestigious liberal arts colleges which were attended by larger proportions of women than men who subsequently earned doctorates in biology and chemistry. Only 12 percent of men who earned doctorates in chemistry had attended the prestigious liberal arts colleges, while 17 percent of women had done so; in biology the contrast is 10 and 15 percent.

Economics and history have a gender pattern remarkably like that of biology and chemistry. Overall, there are only minor differences favoring men across several types of institutions. These differences again are compensated largely by the prestigious liberal arts colleges, which a larger percentage of women than men in these fields had attended. Only 12 percent of the men but 22 percent of the women who subsequently earned Ph.D.s in economics had attended liberal arts colleges, and in history, only 14 percent of the men but 23 percent of the women had done so.

Psychology, political science, and foreign languages share another gender pattern. In these fields, gender differences show up with respect to the large Comprehensive Universities. A larger proportion of men than women who earned doctorates in these fields had gone to this category of undergraduate institution. This male edge is compensated by a female edge in attending Liberal Arts Colleges I.

English stands alone in showing no significant gender differences in the types of undergraduate institutions that people who earned Ph.D.s had attended.

Overall, it appears that while men earning Ph.D.s in most of these fields still outnumber women by a large margin, the types of institutions that are effective in producing the nation's doctorates in the 1980s did not differ greatly for men and women. Research Universities I are the big producers in all fields for both men and women, although they are more effective in sending men on to mathematics and physics/astronomy. The largest comprehensive colleges and universities are the next most likely to produce Ph.D.s, although again in certain fields (psychology, political science, and foreign languages), these types of institutions are disproportionately effective with men. It is the prestigious liberal arts colleges that stand out for being especially effective with women. In all fields, except English, a larger proportion of women than men who earned Ph.D.s in the 1980s had attended the prestigious liberal arts colleges.

TABLE 1

Earned Degrees in Mathematics Conferred by Institutions of Higher Education by Level of Degree, for Women: 1969-70 to 1988-89

Year	Bachelor's degrees			Master's degrees			Doctor's degrees		
	Total	Women	%Women	Total	Women	%Women	Total	Women	%Women
1969-70	27,422	10,265	37	5,636	1,670	30	1,236	96	8
1970-71	24,801	9,432	38	5,191	1,518	29	1,199	96	8
1971-72	23,713	9,259	39	5,198	1,543	30	1,128	89	8
1972-73	23,067	9,271	40	5,028	1,503	30	1,068	102	8
1973-74	21,635	8,844	41	4,834	1,497	31	1,031	100	10
1974-75	18,181	7,595	42	4,327	1,422	33	975	110	11
1975-76	15,984	6,509	41	3,857	1,310	34	856	94	11
1976-77	14,196	5,893	41	3,695	1,299	35	823	109	13
1977-78	12,569	5,171	41	3,373	1,145	34	805	124	15
1978-79	11,806	4,907	42	3,036	1,051	35	730	122	17
1979-80	11,378	4,816	42	2,860	1,032	36	724	100	14
1980-81	11,173	4,781	43	2,569	877	34	728	112	15
1981-82	11,708	5,058	43	2,731	910	33	720	96	13
1982-83	12,557	5,498	44	2,839	980	34	701	113	16
1983-84	13,342	5,914	44	2,749	954	35	698	115	16
1984-85	15,267	7,036	46	2,888	1,011	35	688	106	15
1985-86	16,388	7,616	46	3,171	1,116	35	729	121	17
1986-87	16,626	7,726	46	3,327	1,301	39	740	125	17
1987-88	16,122	7,460	46	3,434	1,377	40	749	121	16
1988-89	15,439	7,106	46	3,431	1,370	40	861	156	18

Sources: Grant, W. Vance and Lind, C. George, *Digest of Education Statistics*, 1979, pp.120-21; Grant, W. and Elden, Leo J., *Digest of Education Statistics*, 1980, p.123; U.S. Department of Health, Education and Welfare, National Center for Education Statistics, reports on *Earned Degrees Conferred*, 1980, pp.120-24; National Science Foundation, *SRS*, 1990, pp.133-135, 141-143, 146-148; National Research Council *Survey of Earned Doctorates*, 1990.

TABLE 2

Earned Degrees in Mathematics Conferred by Institutions of Higher Education, by Level of Degree, for Men: 1969-70 to 1988-89

Year	Bachelor's degrees			Master's degrees			Doctor's degrees		
	Total	Men	%Men	Total	Men	%Men	Total	Men	%Men
1969-70	27,442	17,117	63	5,636	3,966	70	1,236	1,140	92
1970-71	24,801	15,369	62	5,191	3,673	71	1,199	1,106	92
1971-72	23,713	14,454	61	5,198	3,655	70	1,128	1,039	92
1972-73	23,067	13,796	60	5,028	3,525	70	1,068	966	90
1973-74	21,635	12,791	59	4,834	3,337	69	1,031	931	90
1974-75	18,181	10,586	58	4,327	2,905	67	975	865	89
1975-76	15,984	9,475	59	3,857	2,547	66	856	762	89
1976-77	14,196	8,303	58	3,695	2,396	65	823	714	87
1977-78	12,569	7,398	59	3,373	2,228	56	805	681	85
1978-79	11,806	6,899	58	3,036	1,985	65	730	608	83
1979-80	11,378	6,562	58	2,860	1,828	64	724	624	86
1980-81	11,173	6,392	57	2,569	1,692	66	728	616	85
1981-82	11,708	6,650	57	2,731	1,821	67	720	624	87
1982-83	12,557	7,059	56	2,839	1,859	65	701	588	84
1983-84	13,342	7,428	56	2,749	1,795	65	698	583	84
1984-85	15,267	8,231	54	2,888	1,877	65	688	582	85
1985-86	16,388	8,772	53	3,171	2,055	65	729	608	83
1986-87	16,626	8,900	53	3,327	2,026	61	740	615	83
1987-88	16,122	8,662	54	3,434	2,057	60	749	628	84
1988-89	15,439	8,333	54	3,431	2,061	60	861	705	82

Sources: Grant, W. Vance and Lind, C. George, *Digest of Education Statistics*, 1979, pp.120-21; Grant, W. and Elden, Leo J., *Digest of Education Statistics*, 1980, p.123; U.S. Department of Health, Education and Welfare, National Center for Education Statistics, reports on *Earned Degrees Conferred*, 1980, pp.120-24; National Science Foundation, *SRS*, 1990, pp.133-135, 141-143, 146-148; National Research Council *Survey of Earned Doctorates*, 1990.

TABLE 3

Earned Degrees in Physics Conferred by Institutions of Higher Education, by Level of Degree, for Women: 1969-70 to 1988-89

Year	Bachelor's degrees			Master's degrees			Doctor's degrees		
	Total	Women	%Women	Total	Women	%Women	Total	Women	%Women
1969-70	5,320	327	6	2,200	157	7	1,439	37	2
1970-71	5,071	342	7	2,188	150	7	1,482	43	3
1971-72	4,634	320	7	2,033	159	8	1,344	43	3
1972-73	4,259	310	7	1,747	113	6	1,338	51	4
1973-74	3,952	334	8	1,655	135	8	1,115	49	4
1974-75	3,706	359	10	1,574	124	8	1,080	52	5
1975-76	3,544	388	11	1,451	132	9	997	45	4
1976-77	3,420	358	10	1,319	126	9	945	55	6
1977-78	3,330	369	11	1,294	123	9	873	49	6
1978-79	3,337	399	12	1,319	135	10	918	66	7
1979-80	3,396	434	13	1,192	118	10	830	63	8
1980-81	3,441	432	12	1,294	115	9	906	62	7
1981-82	3,475	461	13	1,284	156	12	912	68	7
1982-83	3,800	483	13	1,370	162	12	928	59	6
1983-84	3,921	560	14	1,535	194	13	982	67	7
1984-85	4,111	561	14	1,523	190	12	980	91	9
1985-86	4,189	611	15	1,501	224	15	1,078	100	9
1986-87	4,324	695	16	1,543	243	16	1,137	107	9
1987-88	4,103	611	15	1,681	253	15	1,173	114	10
1988-89	4,437	642	15	1,739	291	17	1,165	102	9

Sources: Grant, W. Vance and Lind, C. George, *Digest of Education Statistics*, 1979, pp.120-21; Grant, W. and Eiden, Leo J., *Digest of Education Statistics*, 1980, p.123; U.S. Department of Health, Education and Welfare, National Center for Education Statistics, reports on *Earned Degrees Conferred*, 1980, pp.120-24; National Science Foundation, *SRS*, 1990, pp.133-135, 141-143, 146-148; National Research Council *Survey of Earned Doctorates*, 1990.

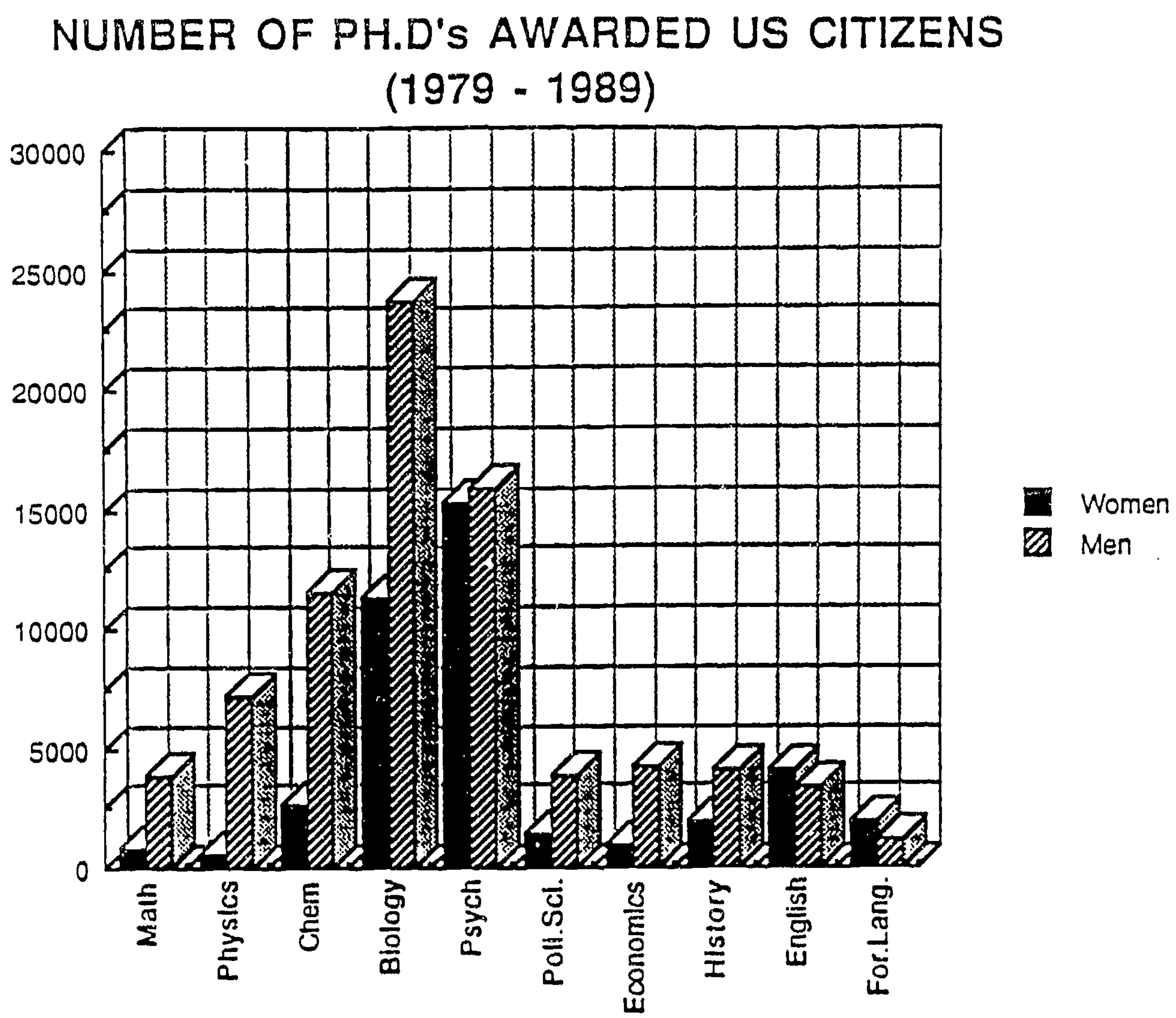
TABLE 4

Earned Degrees in Physics Conferred by Institutions of Higher Education, by Level of Degree, for Men: 1969-70 to 1988-89

Year	Bachelor's degrees			Master's degrees			Doctor's degrees		
	Total	Men	%Men	Total	Men	%Men	Total	Men	%Men
1969-70	5,320	4,993	94	2,200	2,043	93	1,439	1,402	97
1970-71	5,071	4,729	93	2,188	2,038	93	1,482	1,439	97
1971-72	4,634	4,314	93	2,033	1,874	92	1,344	1,310	97
1972-73	4,259	3,949	93	1,747	1,634	93	1,338	1,297	96
1973-74	3,952	3,618	91	1,655	1,520	92	1,115	1,068	96
1974-75	3,706	3,347	90	1,574	1,450	92	1,080	1,028	95
1975-76	3,544	3,156	89	1,451	1,319	91	997	952	95
1976-77	3,420	3,062	89	1,319	1,193	90	945	890	94
1977-78	3,330	2,961	89	1,294	1,171	90	873	824	94
1978-79	3,337	2,938	88	1,319	1,184	90	918	852	93
1979-89	3,396	2,962	87	1,192	1,074	90	830	767	92
1980-81	3,441	3,009	87	1,294	1,179	91	906	844	93
1981-82	3,475	3,014	87	1,284	1,128	88	912	844	92
1982-83	3,800	3,317	87	1,370	1,208	88	928	869	94
1983-84	3,921	3,361	86	1,535	1,341	87	982	915	93
1984-85	4,111	3,550	86	1,523	1,333	87	980	889	91
1985-86	4,189	3,578	85	1,501	1,277	85	1,078	978	91
1986-87	4,324	3,629	84	1,543	1,300	84	1,137	1,030	91
1987-88	4,103	3,492	85	1,681	1,428	85	1,173	1,059	90
1988-89	4,347	3,705	85	1,739	1,448	83	1,165	1,063	91

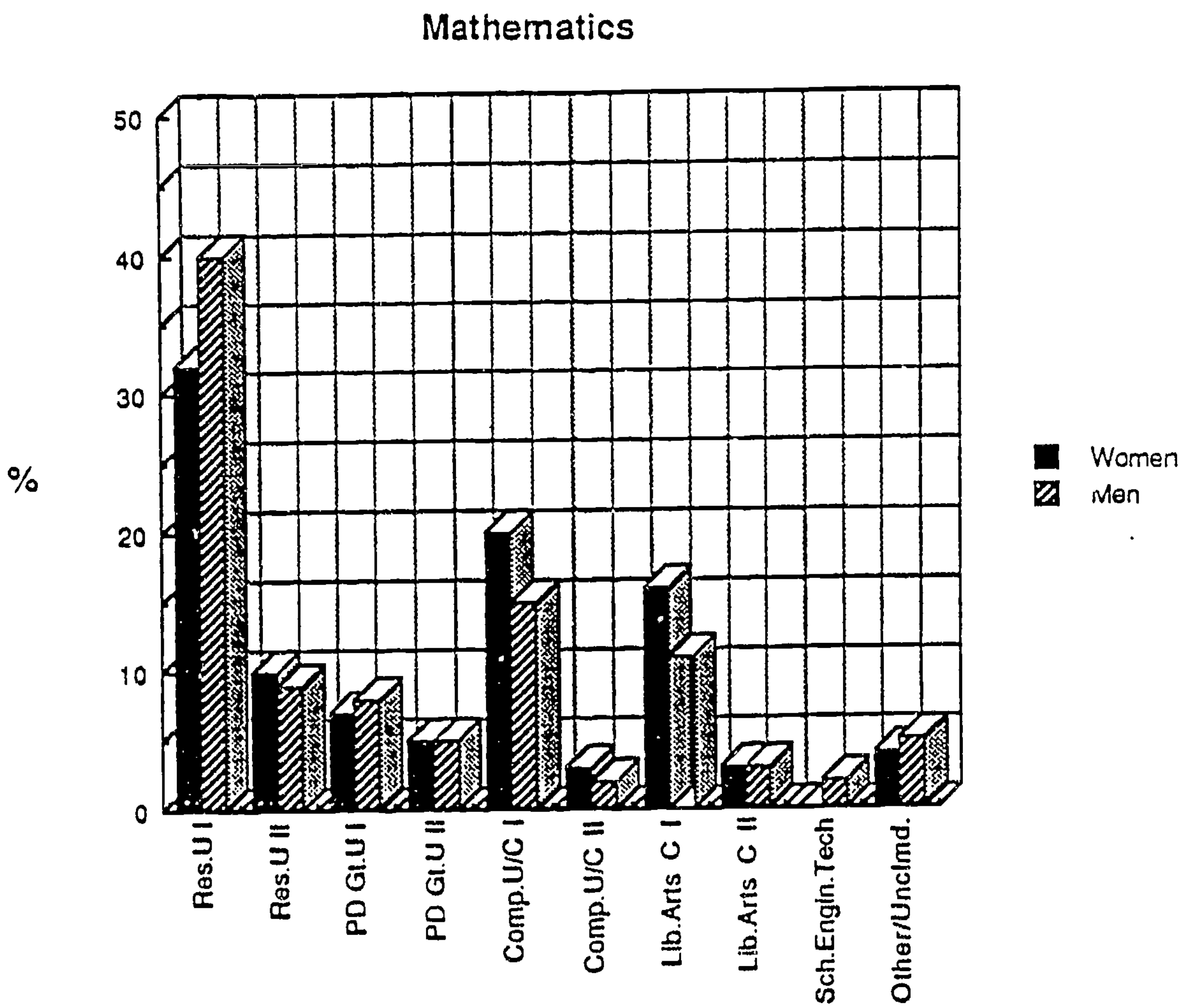
Sources: Grant, W. Vance and Lind, C. George, *Digest of Education Statistics*, 1979, pp.120-21; Grant, W. and Elden, Leo J., *Digest of Education Statistics*, 1980, p.123; U.S. Department of Health, Education and Welfare, National Center for Education Statistics, reports on *Earned Degrees Conferred*, 1980, pp.120-24; National Science Foundation, *SRS*, 1990, pp.133-135, 141-143, 146-148; National Research Council *Survey of Earned Doctorates*, 1990.

FIGURE 1



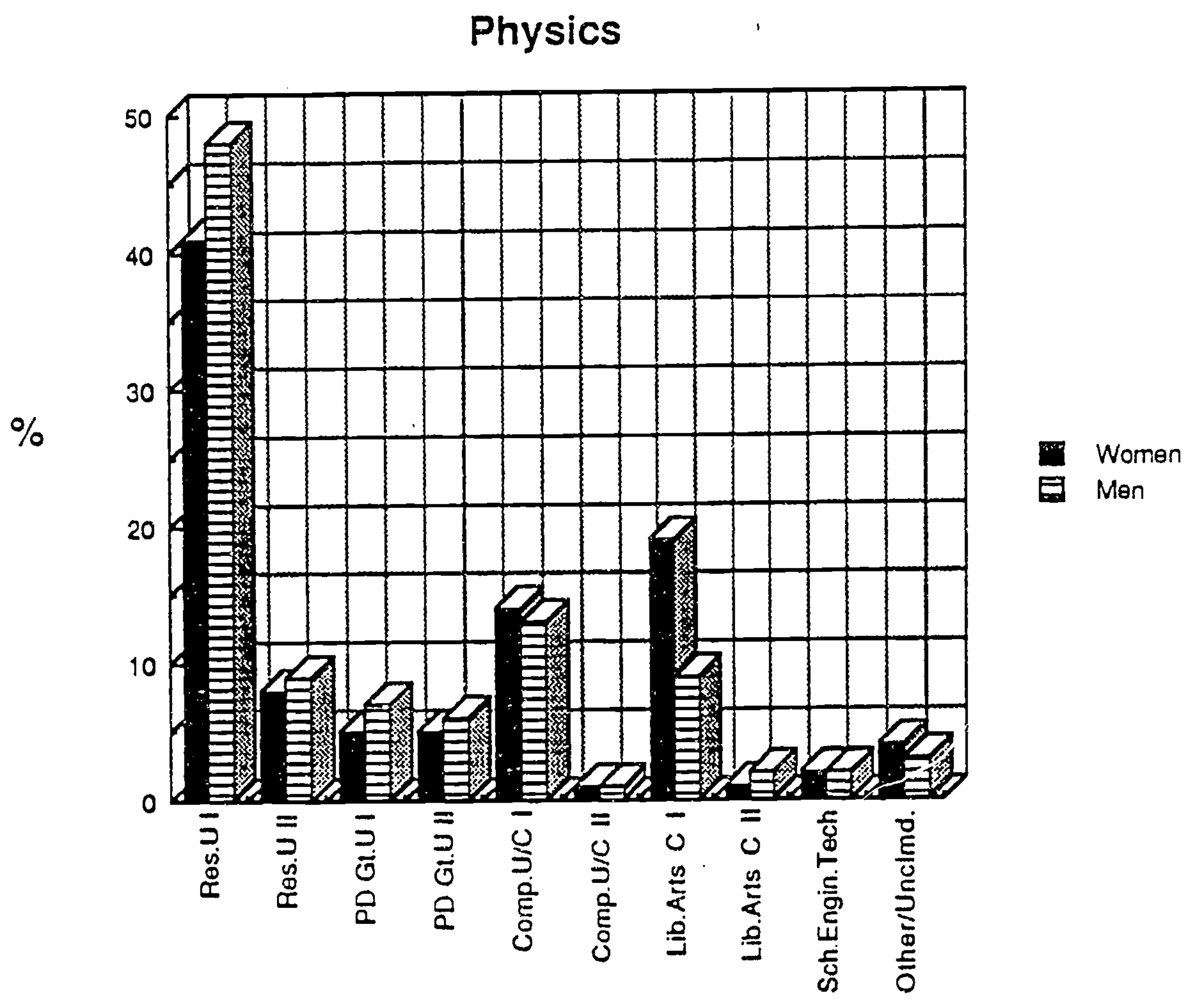
Source: Survey of Earned Doctorates conducted by the National Research Council and sponsored by five federal agencies (NSF, NIH, NEH, USDA, ED)

FIGURE 2a
Proportion of Ph.D. Degree Recipients
Who Had Attended Ten Types of
Undergraduate Degree Institutions
(Decade of the 1980's)



Source: Survey of Earned Doctorates conducted by the National Research Council and sponsored by five federal agencies (NSF, NIH, NEH, USDA, ED)

FIGURE 2b



Physics
50
40
30
20
10
0
%
Women
Men
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.

FIGURE 2c

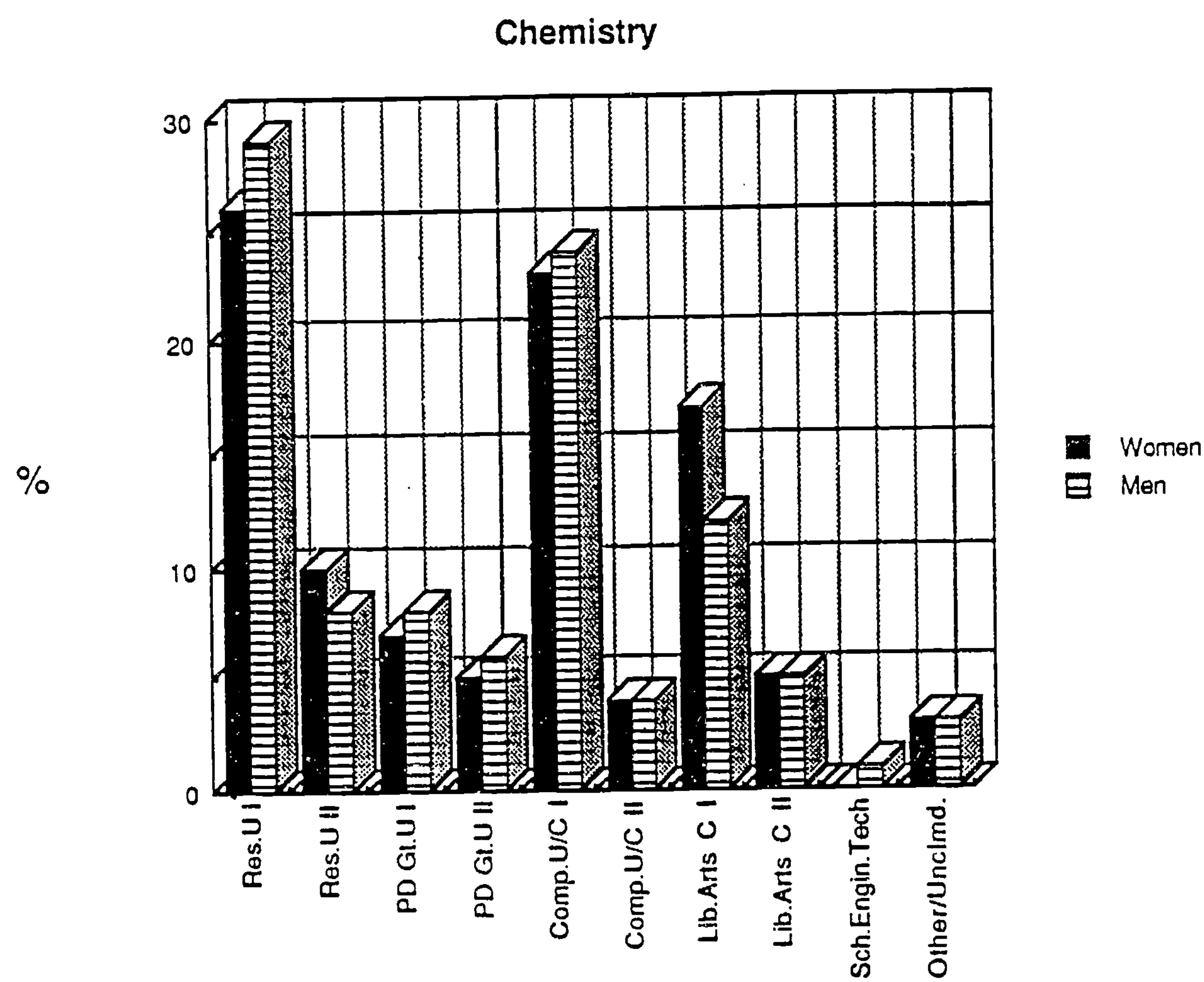

Chemistry
%
30
20
10
0
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.
Women
Men

FIGURE 2d

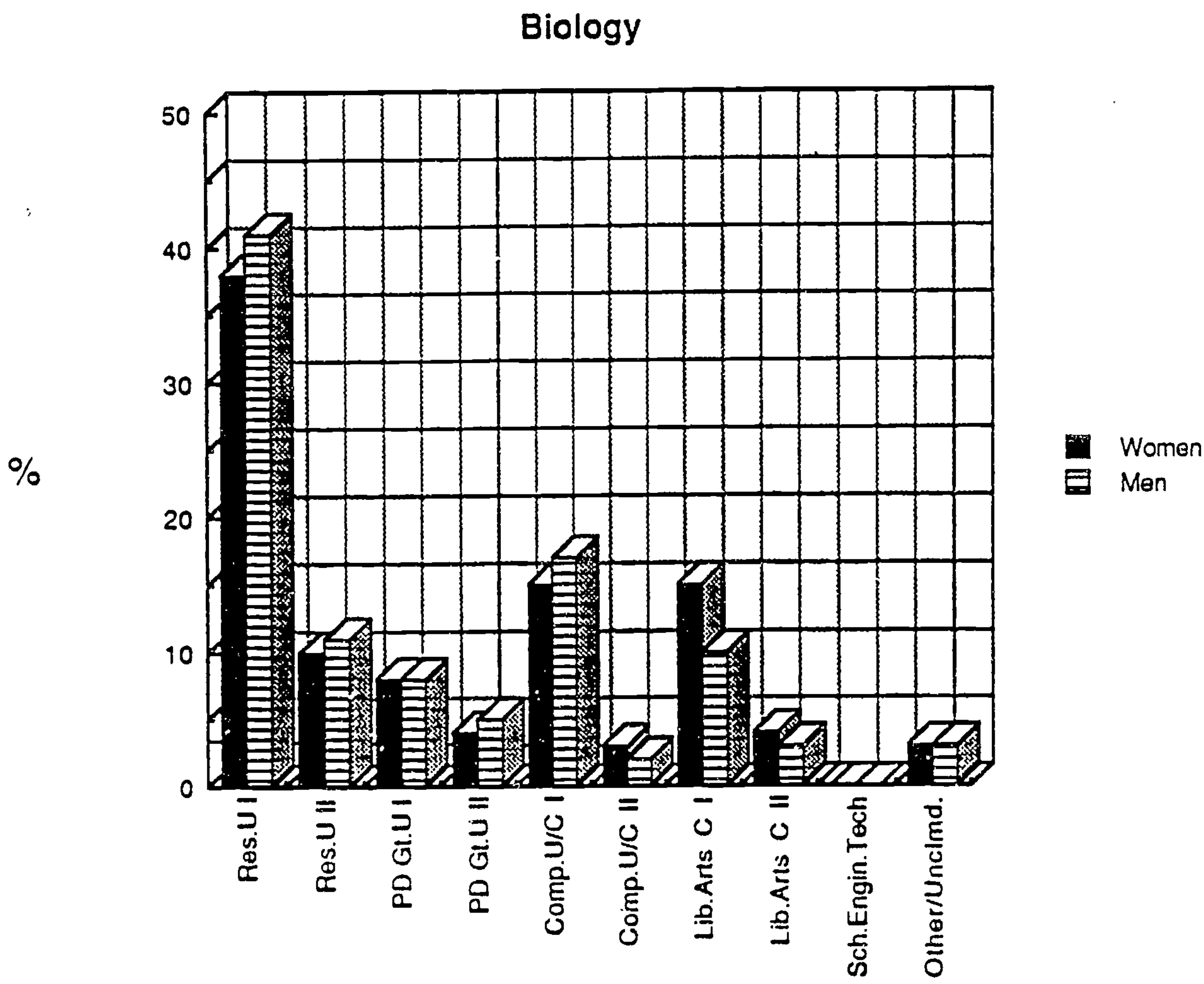
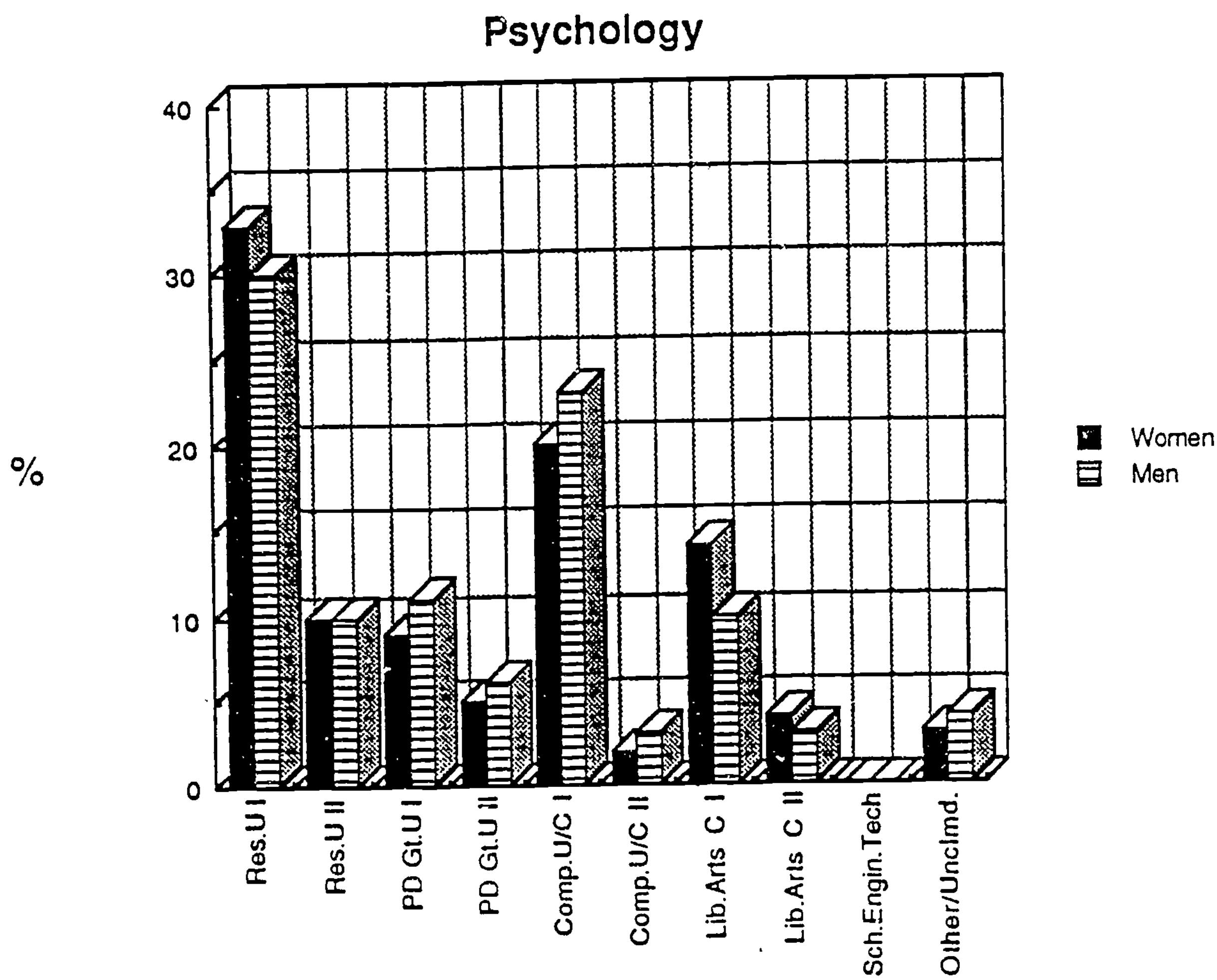

Biology
%
50
40
30
20
10
0
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.
Women
Men

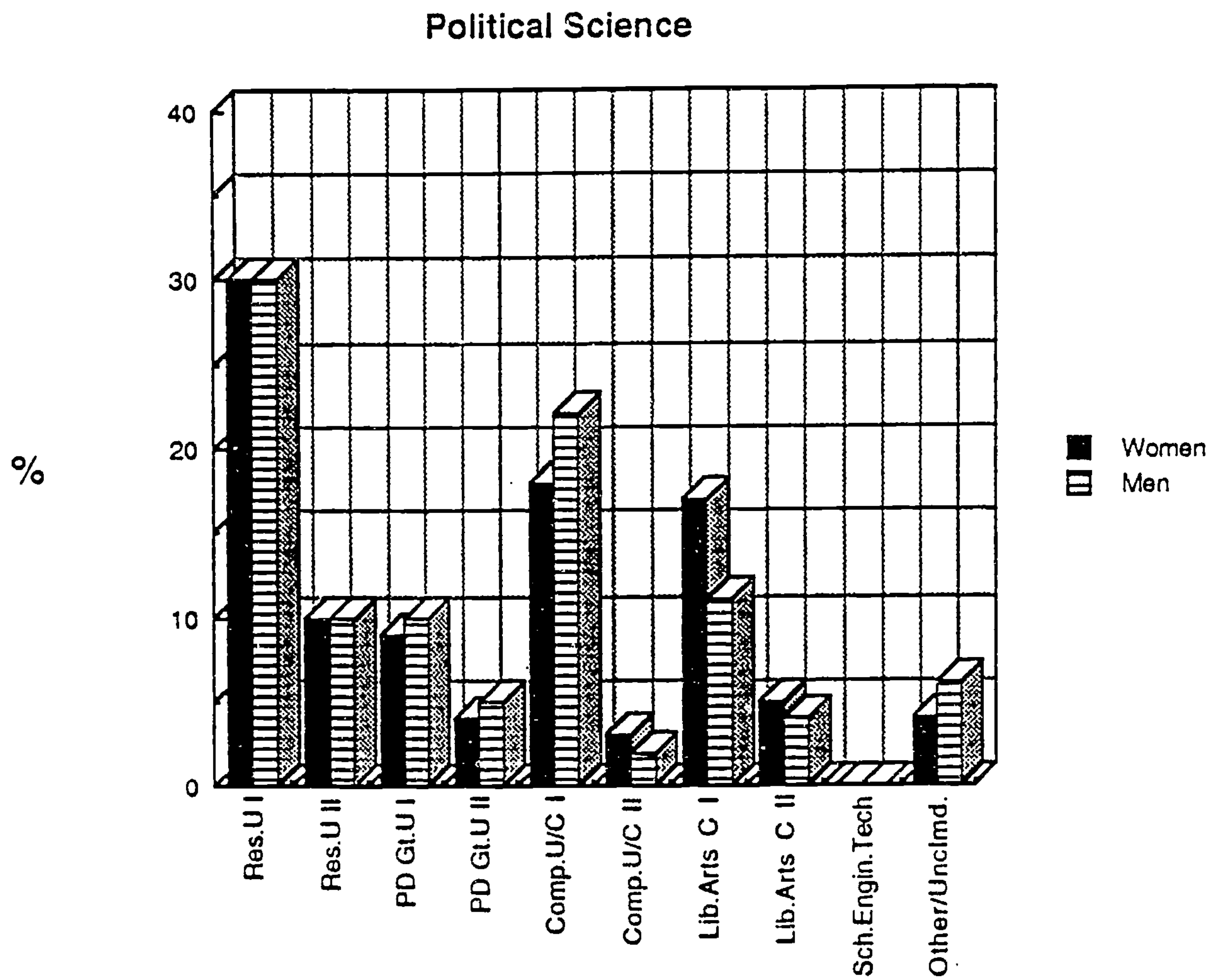
FIGURE 2e



Psychology
40
30
20
10
0
%
Women
Men
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.

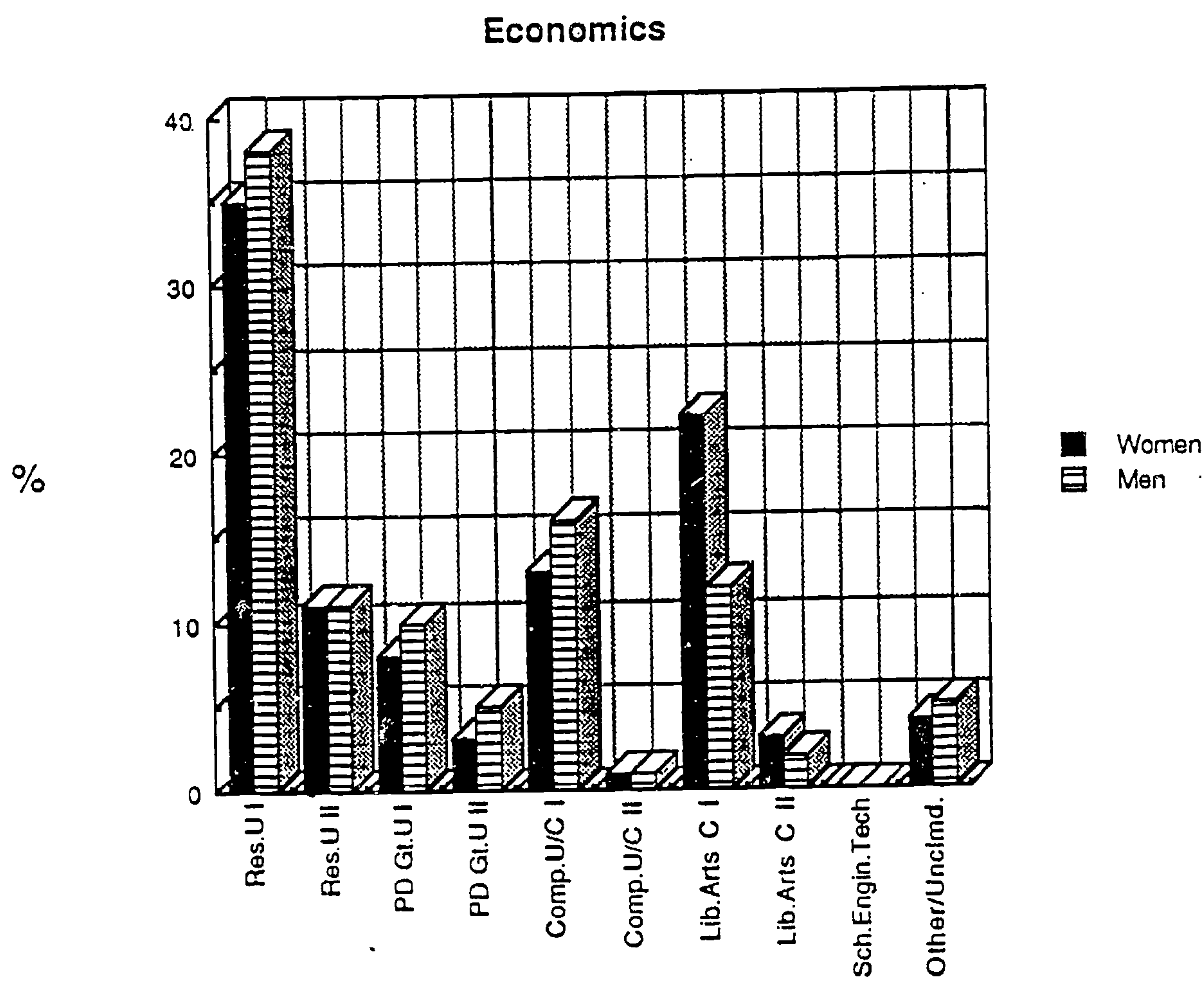
30

FIGURE 2f



Political Science
%
40
30
20
10
0
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.
Women
Men

FIGURE 2g



Economics
40
30
20
10
0
%
Women
Men
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.

62

FIGURE 2h

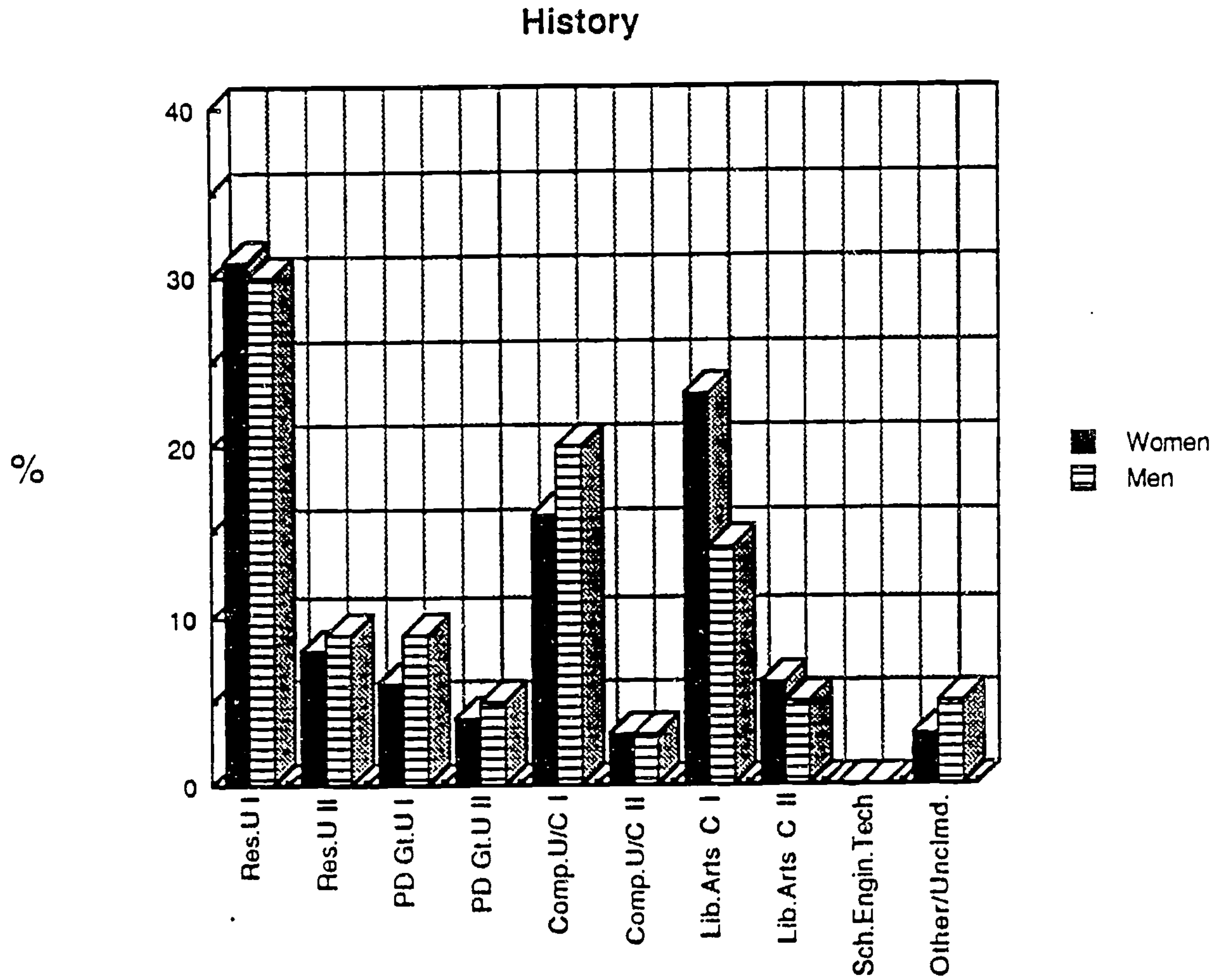

History
%
40
30
20
10
0
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.
Women
Men

FIGURE 2i

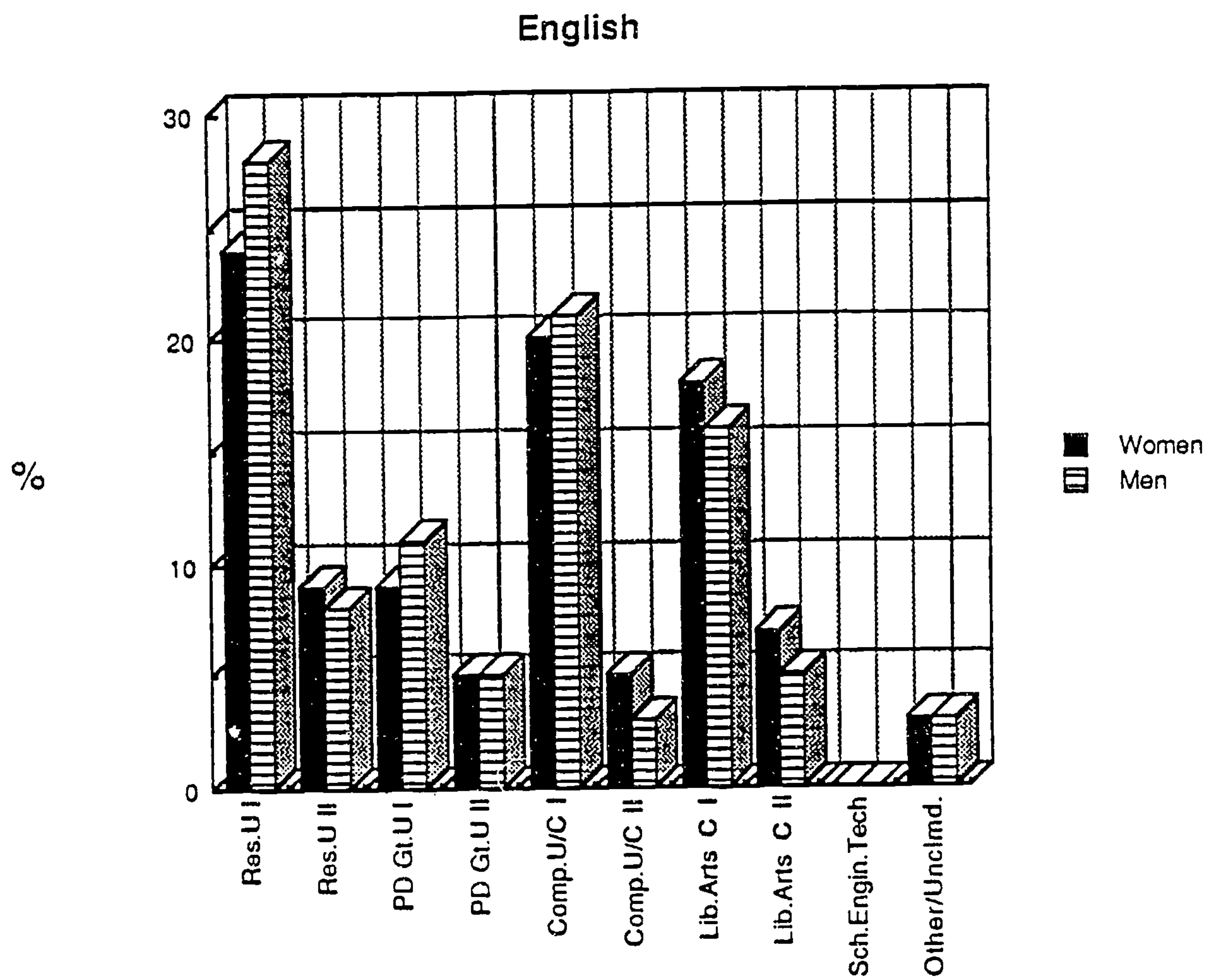
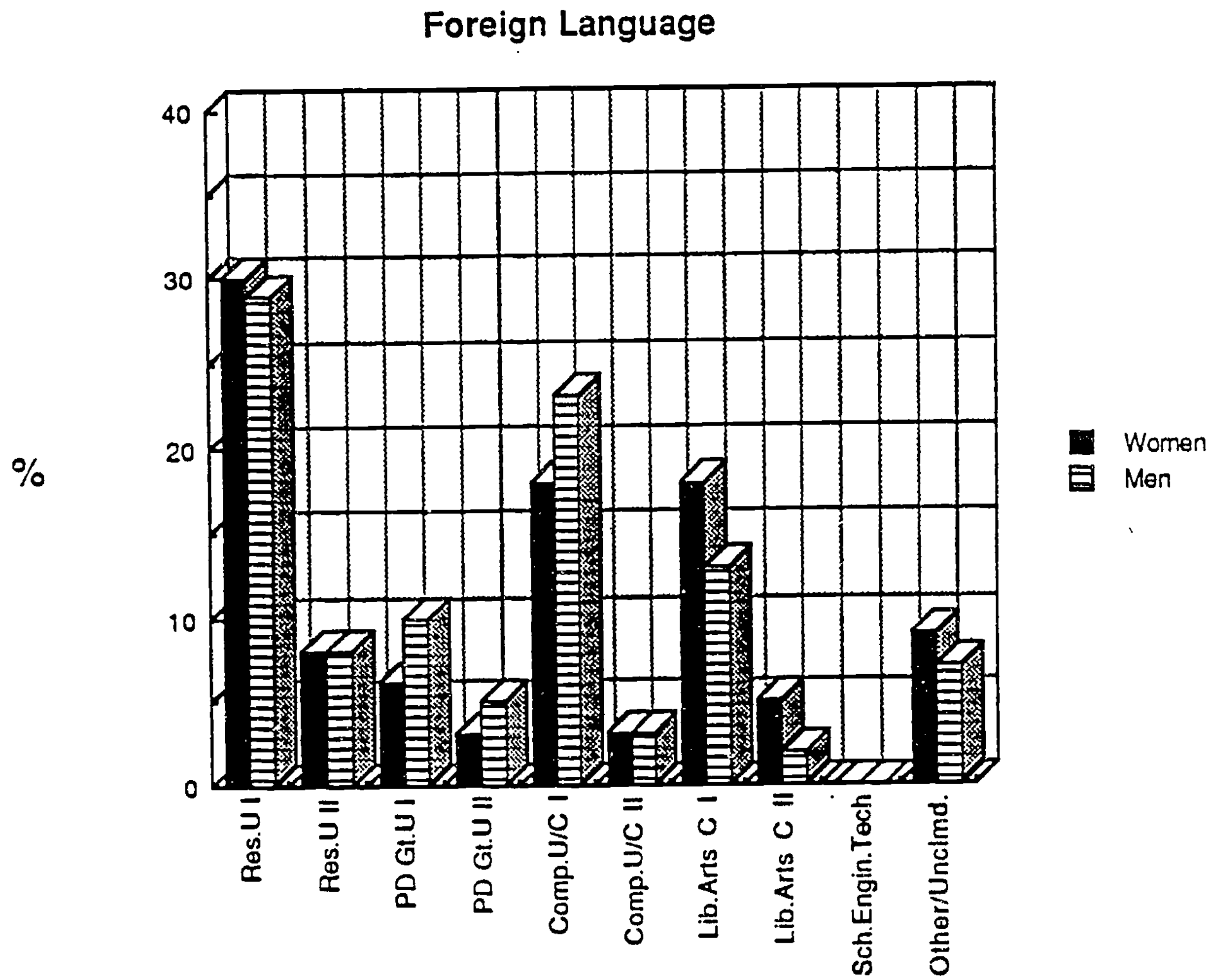

English
30
20
10
0
%
Women
Men
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.

FIGURE 2j



Foreign Language
%
40
30
20
10
0
Res.U I
Res.U II
PD Gt.U I
PD Gt.U II
Comp.U/C I
Comp.U/C II
Lib.Arts C I
Lib.Arts C II
Sch.Engin.Tech
Other/Unclmd.
Women
Men

B. Enrollment and Attrition Studies: Making the Decision to Pursue Mathematics and Physical Science

Studies have attempted to pinpoint the exact timing of the decision to select mathematics or physical science as a college major and to identify what factors affect that choice. As girls progress through the school system, they experience both internal and environmental pressures which increase or diminish their interest in a science career, but unless a girl elects sufficiently difficult mathematics courses in high school, she will not arrive in college with the option of majoring in science. High school mathematics courses have been described as a "critical filter" which can block the entrance into science disciplines. Brickhouse, Carter, and Scantlebury (1990) describe the under-representation of women in chemistry and point to mathematics as the gatekeeper for chemistry and the other physical sciences. In a study of high ability students at one selective liberal arts college, Lovely (1987) noted that high school preparation is the key to increasing female participation in the sciences. He found a link between high Mathematics SAT and Advanced Placement (AP) test scores in high school, and choice of science majors in college.

In the past, patterns of enrollment in high school mathematics classes showed that girls take fewer and less advanced courses. In 1988 the Educational Testing Service analyzed the course-taking patterns of college-bound seniors. They found that equal percentages of each gender began the mathematics sequence with the first algebra course (97% of both girls and boys). However, as the students progressed through the sequence fewer and fewer girls remained. In the terminal calculus course only 15% of the original females versus 21% of the males were still enrolled. The most recent data on AP test takers indicate, however, that women have nearly reached parity with men.

Investigators have suggested a number of possible reasons that girls elect fewer mathematics and science courses than boys. These include the characterization of these fields as masculine (Ehrhardt and Sandler, 1987); lack of parental encouragement (Kahle, 1983; Jacobs and Eccles, 1985; Campbell, 1986); and lack of teacher and counselor encouragement (Haven, 1972; Casserly, 1975; Luchins, 1976; Sherman, 1979; Eccles-Parsons, 1984; Wilkinson and Marrett, 1985; Andrews, 1989; Erickson et al., 1987). Each of these factors will be discussed individually later. Interestingly, in spite of the difficulties involved in changing societal behavior patterns, a recent program in Minnesota shows that negative influences can be countered by aggressive intervention. The participation and retention of girls in the University of Minnesota Talented Youth Mathematics Program improved dramatically when the program targeted informational counseling, and support issues (Keynes, 1991).

Comparisons of college women majoring in mathematics and science and those majoring in other fields show that the former group have more prior preparation in mathematics and science; although they are somewhat less prepared than men who go into mathematics and science. Women choosing mathematics and science disciplines have generally taken more mathematics and science courses in high school than their female age mates choosing other majors (Ehrhardt and Sandler, 1987; Meisel, 1983), and have earned higher high school grades than other women (NSF, 1990). Women science majors are also more likely to have taken Advanced Placement examinations in high school (Lovely, 1987; Meisel, 1983; Manis et al, 1989). The mathematics SAT scores of women science majors are also higher than for those for women in other majors, although the scores of women science majors are still lower than scores of male science majors (Manis, et al, 1989).

In spite of the potentially serious problem of weaker high school mathematics and science proparation, many young women do enter college with sufficient course work to select a science major. For example, at the University of Michigan in the fall of 1989, 76% of all freshman females and 90% of the freshman males in the College of Literature, Science, and the Arts had completed four years of high school mathematics. But data from the same fall on seniors in Literature, Science, and the Arts shows that only 10% of the women and 18% of the men were mathematics or science concentrators.

Studies done at the University of Michigan explored whether women with an initial interest in science maintain that interest, and whether women who haven't decided on a major are attracted into science during their beginning years in college. The Center for Continuing Education for Women (Manis et al., 1989) found that there was considerable movement by women away from science majors with no corresponding attraction into scientific fields of students who were initially interested in other fields.

The picture for honors students differs somewhat. The study of University of Michigan honor mathematics courses (see Section IV of this report) indicates that the students moving out of natural science are replaced by previously undecided students. Gender does not seem to be an important factor here except that many of the women taking freshmen honors mathematics were already firmly committed to medical careers before coming to college. In the broader group of all women who eventually majored in mathematics or physics, nearly half of them did not come to college with such an intention. It is usual for women to decide to become mathematics teachers or actuaries after they have gone through the entry-level mathematics courses (see U/M graduating seniors in Mathematics and Physics, this report, Section IV).

Initial college courses play a role in determining a woman student's choice of major. University of Michigan women who expressed an initial interest in science were greatly influenced by experiences in their first college science courses (Meisel, 1983). It appears that the subjective quality of the undergraduate experience, as much as the content of the courses, can contribute to the decision to pursue a science career. Ethington, Smart, and Pascarella (1987) found that the undergraduate experience continues to have an influence on women's choices throughout their engineering careers.

There is also some evidence that men's and women's decision processes differ. Women engineers tend to make the decision to pursue engineering later than men. Jagacinski (1987) shows that while more than half of male engineers had decided on an engineering career while still in high school, more than half of the women studied did not choose engineering until they had completed college. These female engineering recruits generally earn higher college grades than do men majoring in engineering (Jagacinski, LeBold and Linden, 1987).

Once a woman has decided to major in science, she is more likely than a male student to complete her bachelor's degree, and with good grades; but many women go no farther. The situation for women entering and completing graduate school is summed up in the pipeline model (Widnall, 1988). Only 20% of the women who enter college prepared to major in science actually choose a science or mathematics major, and these women are only half as likely to obtain a science doctorate as are their male counterparts. The National Science Foundation (1990) reports that women earn just 25% of all master's degrees awarded in the physical sciences and 17% of the doctorates in these same fields. In addition to the under-representation of women earning degrees in the physical sciences and mathematics, NSF (1990) found that the women took longer to complete their degrees than the men did. Proportionately fewer women than men had completed a master's degree in science, mathematics or engineering two years after earning a bachelor's degree in these fields. Similarly, the median time elapsed between completing the bachelor's and the doctorate degree is longer for women than for men. This may suggest that women follow a less direct path from undergraduate study to completion of a graduate degree (Nettles, 1990, and UM Honors Study).

In summary, the evidence in numerous studies shows that fewer women than men earn bachelor's, master's, and doctoral degrees in mathematics and science. The nation must recruit and retain talented young people to these fields, and the problem of how to attract and retain talented women must be seen in this context.

C. Background Characteristics of Women in Science, Mathematics, and Engineering

Comparisons of male and female college students majoring in mathematics, science, and engineering reveal differences in personal background. More women than men in science tend to come from families in which parents have above average levels of education and are involved in science careers. Mothers of women science majors are more likely than mothers of male science majors to be professionals and scientists (Ehrhardt and Sandler, 1987; Meisel, 1983). An exception to this is that more women than men studying engineering technology come from a lower socioeconomic backgrounds (Rudnick, 1984).

D. Studies of Determinants of Women's Achievement in Mathematics and Science

The research on women's achievement in mathematics and science falls generally into three categories: the individual perspective, environmental factors, and the interactionist view. Studies of individual factors generally focus on ability, self-concept, attitudes, interests, values or affect. Studies of environmental factors generally emphasize classroom dynamics, opportunities for internships and social support. The interactionist view combines both internal and external factors and often presents causal models of their respective impact on women's achievement.

Individual Factors

The research on individual factors assumes that barriers to women's achievement in mathematics and the sciences lie within the individual. Sometimes it is argued that women lack mathematics ability or spatial visualization, although other researchers put less emphasis on ability than on motivational factors such as self-confidence, attitude and interest problems.

Intellectual Ability: Because the age at which gender differences in mathematics ability first appears is of critical importance in determining whether gender differences are held to be genetic or learned, most of the literature on ability factors is focused on the elementary or junior high school level.

There are no clear winners in the current debate regarding gender differences in intellectual ability. According to Ethington and Wolfle (1986), there are four primary explanations for the variance in mathematical performance between boys and girls: superior mathematical ability of males compared to females (Benbow and Stanley, 1980, 1983); differences in spatial abilities (Maccoby and Jacklin, 1974); social-psychological factors (Fennema and Sherman, 1977); and different coursework experiences (Ethington and Wolfle, 1984, 1986).

Benbow and Stanley (1980, 1983) are strong advocates of a biological explanation. They believe that biological factors explain gender differences in mathematical reasoning, although their critics contend that Benbow and Stanley have not actually provided biological data to support their view.

Many studies have sought to determine if males and females do perform differently on skills that underlie competence in mathematics. This research on specific mathematical skills shows contradictory evidence. Some conclude that women do perform less well than men. Linn and Petersen (1986) present a comprehensive overview of this literature focusing specifically on gender differences in spatial ability, which many argue is the basis for gender differences in mathematics and science achievement. Using meta-analysis, they discover that most of this research can be distilled into four different perspectives, using concepts such as spatial perception, mental rotation and spatial visualization, therefore providing many different measures. They conclude that there are inconsistent inferences made about gender differences and evidence is largely lacking to make a strong statement in either direction.

Fennema and Sherman (1977) argue that the most important question is what underlies gender differences on skills such as these. They believe that sociocultural experiences are critical. They and others (Linn and Hyde, 1989; Linn and Petersen, 1986; Ethington and Wolfle, 1986; Boli, Allen and Payne, 1985; Goldman and Hewitt, 1976) claim that male-female differences in course preparation primarily explain why men perform better on spatial and problem-solving tasks. The best predictors of success on such tasks are number of mathematics courses taken and intelligence test scores.

Some question whether male and female students differ at all on such mathematical tasks. Goldman and Hewitt (1976) contend that males reliably outperform females on the SAT-M and that lack of mathematical ability evident on this test (whose origin they do not discuss) is a direct cause of the underrepresentation of females as college science majors. They argue that the remedy is to increase the mathematical ability of college women, although they offer no guidelines on how to accomplish this. Other analysts disagree. In a meta-analysis of 100 studies, Hyde, Fennema and Lamon (1990) found that there were few differences in computation, understanding of concepts, or in solutions of complex problems. An examination of age trends suggests slight female superiority in computation in elementary school and middle school which is reversed in favor of men in high school and college. These age effects are less pronounced in recent than in older studies, however. Studies published before 1973 showed greater age effects (d=.31) than those published later (d=.14).

A meta-analysis of possible cognitive differences between males and females comes to a similar conclusion -- that there are only small and declining gender differences on measures of mathematics reasoning and skills, and that differences that favor one gender tend to be offset by differences that favor the other (Linn and Hyde, 1989; Hyde, Fennema and Lamon, 1990). For example, Maier and Casselman (1971) find that males tend to outperform females on quantitative types of problems such as those found on the SAT-M ("making essential distinctions"), while females outperform males on problems requiring abstract reasoning ("idea-getting").

Studies of performance in college courses also show contradictory evidence. Boli, Allen and Payne (1985) report that men in college courses in introductory chemistry and mathematics perform better than women, and that this difference largely reflects women's weaker background in mathematics. On the other hand, DeBoer (1984b) reports that women perform better in college mathematics and science courses even when measures of preparation are taken into account.

In summary, the literature continues to show mixed results, although there is growing agreement that gender differences in specific skills and in test performance are declining. Many analysts also agree that the stronger preparation of males in high school primarily accounts for what gender differences still exist at the college level.

Self-Concept: The self-concept is a global construct composed of various affective elements. Two of the affective components that often appear in the literature on how women approach mathematics and science are self-confidence and sex-role congruency.

i) Confidence: The impact of confidence on mathematics achievement at the elementary and high school level has been studied extensively. Fennema and Sherman (1977, 1978; Sherman and Fennema, 1977) conclude that gender differences in achievement and confidence are usually found together, in favor of males. Of all the affective variables they studied, self-confidence was the most strongly correlated with mathematics achievement (r=.40). In addition, gender differences in confidence were found even when there were no differences in achievement. Females report lower self-confidence even when they perform as well as males. Furthermore, in a longitudinal study of grade school students, confidence in the sixth grade was predictive of mathematics achievement for females six years later (Meyer and Koehler, 1990).

Confidence has also been studied at the college level (Lenney, 1976, 1977, 1981; Lenney, Browning and Mitchell, 1980; Lenney and Gold, 1982; Lenney, Gold and Browning, 1983). In general, this research argues that self-confidence is highly contextualized and specific rather than global in nature. Signorella (1984) notes that women are not always lower in self-confidence than men, that self-confidence varies by situation. It depends on the nature of the specific task (a specific ability area denoting its sex linkage like mathematics or physics). It also depends on the presence and clarity of performance feedback. When women get clear information about their abilities, they are as self-confident as men. It further depends on whether or not social comparison takes place. Women have lower self-confidence if they know they are to be compared with others or evaluated by them.

A study that shows the importance of situational factors was carried out by Lenney (1981). She varied ability area and social cues. Three types of tasks were used to vary ability area: a "male" ability task (spatial-mechanical visualization); two "female" ability tasks (verbal skills and interpersonal perceptiveness); and a "neutral" ability (creative skills). To vary social cues, subjects were asked to make estimates of their own performance and that of the "average undergraduate" (gender unspecified), "the average male undergraduate", or the "average female undergraduate". Even though their actual performance scores did not differ from those of the men, women expressed significantly lower levels of self-confidence on the spatial visualization and creativity tests. They also compared themselves significantly less favorably than men when estimating their performance and that "of the average male undergraduate" on the spatial-mechanical test. Lenney concludes that women's self-confidence is unduly affected by situational comparison cues.

Lenney, Gold, and Browning (1983) have also tested the social comparison hypothesis by varying the presumed level of ability of a same-sex partner. In this study, the subjects were led to believe that they would be working with a partner who was either highly competent or of average competence. This manipulation had powerful effects on gender differences. Gender differences appeared only when subjects anticipated working with partners who were highly competent. Women chose a less difficult task than men, performed less well than men, and stated lower self-evaluations than men when they thought they would be paired with a highly competent partner. Lenney suggests that women have an unstable and vulnerable appraisal of self rather than a generalized low level of self-confidence.

Using a twist on the concept of self-confidence, Betz and Hackett (1983) pursue Bandura's theory of self-efficacy by investigating if mathematics self-efficacy affects choice of a science career among college undergraduates. Self-efficacy was a strong indicator of persistence along a scientific path. Mathematics self-efficacy is shaped by successful performance in mathematics tasks and then affects the student's choices.

Another perspective on self-confidence was examined in a five-year longitudinal study of high school valedictorians and salutatorians (Arnold, 1987). Upon entering college, equal proportions (20%) of males and females among these top performing students considered themselves to be far above average in intelligence. By their sophomore year, however, only 4% of the women, compared to 22% of the men, still thought of themselves that way. This drop in the women's self-confidence took place even though they had achieved as high grades as the men in the first year at college.

Not only are women vulnerable to social comparison and evaluation, they are also more sensitive than men to supportive features of the academic environment (Stansbury, 1986). Looking specifically at graduate students in engineering and science, self-confidence and assertiveness were related to several situation variables for women but not for men. Perceived stress in graduate school was the strongest predictor of women's assertiveness and confidence. Quality of the relationship with an advisor was also a significant predictor of both qualities for women (and for self-confidence of men). The author suggests that improving quality of relations between students and advisors, specifically the frequency of meeting and the ease of communication in this relationship, would go a long way in raising graduate women's self-confidence in themselves and in their commitments to their doctoral training.

In summary, this research shows that confidence is clearly an important influence in mathematics and science achievement for females. It influences achievement behavior at both early and later stages of development. Women are more attuned to the implications of the environment and can only match the confidence of their male peers when the environment does not emphasize social comparison, when women work at tasks the society does not define as typically male, and when women receive incontrovertible feedback that they are performing well.

ii) Sex-role congruency: Studies of sex-role congruency show that females tend to see mathematics as a "masculine" endeavor that is inconsistent with a woman's role.

The research literature on the early years reveals that children as early as third grade perceive mathematics as belonging in the male domain (Boswell, 1985). This continues in high school, although males are more likely than females to heavily stereotype mathematics as "masculine" (Fennema and Sherman, 1977, 1978). This means that high school females will interact with males who generally hold this gendered conception of mathematics. To pursue mathematics, females thus have to counteract not only their own stereotypes but also the even stronger stereotypes of their male peers.

These sex-role stereotypes go on affecting women in mathematics and science long after high school. Women mathematicians who have recently earned the Ph.D. soundly agree that society stereotypes women in their field (Boswell, 1985). Eight-three percent of them, compared to 74% of female English Ph.D.s and 65% of female psychology Ph.D.s, felt that women in their field were stereotyped. It is important to note, however, that the women mathematicians did not perceive themselves to be more "masculine" than the women who earned Ph.D.s in these other fields. In fact, they scored the least masculine on the Bem Sex Role Inventory (Boswell, 1985). There is some contradictory evidence about self-conceptions of masculinity and femininity in other studies, however. Other researchers, using different instruments and different populations, have found that women who aspire to careers traditionally held by men (including mathematics and science) perceive themselves as more "masculine" (Baker, 1987; Hollinger, 1983) and sometimes as less "feminine" (Hollinger, 1983) than women who intend to go into female-dominated careers.

Overall, the research on sex-role congruency shows that role evaluations influence women in both entering and persisting in particular academic subjects. Gender stereotypes put a value on a subject (and a career) that is not easily dismissed because the stereotypes are so widely held in the social environment.

Self-confidence and sex-role congruency, moreover, are intertwined in their effects. A woman will not easily venture into a sex-role inappropriate realm, and therefore must have unusually strong confidence in her abilities to counter these societal definitions of appropriate roles for men and women. To be effective, interventions simultaneously will have to build the confidence of women for mathematics and science tasks and the conviction among their peers, advisors, teachers, and parents that these tasks are appropriate and important for women as well as men.

Affective Factors: The importance of affect in learning mathematics and science is appreciated more now that cognitive psychology has focused more attention on the role of affect in thinking processes. A group of scholars influenced by Mandler's theory of emotion (Mandler, 1984) are taking up a number of issues in the relationship between cognition (thinking) and affect (a range of concepts including beliefs, attitudes/preferences and emotions).

Affective concepts provide a useful framework for delineating research on whether and how men's and women's personal dispositions influence their choices and achievements in mathematics and science. A common (though not universal) point of view about the differentiation of these concepts may be helpful

i) Beliefs: Two sets of beliefs seem to influence the learning of mathematics. The first concerns students' beliefs about mathematics itself; the second their beliefs about themselves and their relationship to mathematics (already reviewed under the self-concept section above).

With respect to beliefs about mathematics, research shows that students generally concur that mathematics is important, difficult, and based on rules (McLeod, 1989a). Schoenfeld (1985) and Silver (1985) conclude that some of these views of mathematics, by cutting down persistence and search for novel solutions, may weaken students' abilities to solve non-routine problems. The belief that mathematical problems can and should be solved quickly is particularly dysfunctional since students who believe this to be true often fail to stick with a problem and fail to look for new strategies when an immediate solution does not appear. Similarly, the belief that mathematics requires knowledge and application of rules often interferes with "doing" mathematics well. In observing the mathematics problem solving of seventh graders, Lester and his colleagues (1989) have found that this belief about rules prompts students to try out previously learned operations rather than to understand the problem.

Only a few studies of beliefs about mathematics have focused on gender. These few generally use the Fennema-Sherman (1976) belief scales to measure whether male and female students hold different beliefs about mathematics. Usually the studies show that men more than women believe that mathematics is a useful field, and both groups agree that mathematics is a male domain. McLeod concludes that these kinds of beliefs "are important both for gender-related differences in mathematics achievement and for the related differences between females and males in affective responses to mathematics." (McLeod, 1989a, 247) Dorothy Buerk, a teacher of college-level mathematics, offers anecdotal evidence supporting McLeod's conclusion. She argues that math-avoidant women students too frequently believe that mathematics is absolute and a collection of right answers with correct methods and exact symbols -- beliefs that inhibit mathematical reasoning and learning.

ii) Attitudes and Preferences: The attitudes and preferences of students regarding mathematics and science have been widely studied, although gender has not been consistently or carefully addressed in most of these studies. Steinkamp and Maehr (1984), who carried out a comprehensive review of the literature containing comparisons of boys and girls on various measures of motivation in science, conclude: that there is an appalling lack of research that responsibly addresses gender differences; that with few exceptions, researchers do not treat the gender issue in a straightforward manner; and that many studies fail to report even minimal information for the calculation of effect size. But despite statistical and conceptual weaknesses in much of this research, these authors draw three conclusions from the past research: first, that gender differences in attitudes and preferences are smaller than is generally assumed; second, that differences are larger for actual achievement than for these motivational factors; and third, that when attitude/preference differences do occur, with few exceptions, they tend to favor males.

Other researchers concur that gender differences in attitudes and preferences are small, and certainly smaller than would be expected from the different proportions of men and women who pursue mathematics and science careers. In one of the best known and largest studies of postwar engineering and science graduates of a large midwestern university, Perrucci (1970) found that men, women "careerists" and women "non-careerists" differed in their work profiles (work place, principal function of their positions, supervisory and technical responsibility) but not in their work values.

A study of juniors and seniors in eight four-year colleges and universities located in the south-Atlantic region (Thomas, 1986) also found few differences in the attitudes and preferences of males and females at the time they were in high school. Males and females did not differ on scales measuring how much they liked mathematics and science, and the determinants of their attitudes were remarkably similar. The most important factors for both groups were having had science hobbies as children, having received encouragement by important people in their lives, having achieved good grades in high school, and having participated in high school mathematics clubs. Simpson and Oliver (1990) take the study of attitudes and preferences back to the junior high school level. They administered questionnaires to 4500 sixth through ninth graders in a central North Carolina school district. "Gender differences were studied throughout this investigation but were not found to be as significant as expected.... While there were minor differences, results from this study suggest that male and female adolescent students feel and behave toward science in much the same way."

Some studies have focused on different sub-groups of female students. One, carried out by Julia Sherman (1982, 1983) using the Fennema-Sherman Mathematics Attitudes Scales and intensive interviews, goes into the experiences and attitudes of high school girls who had taken four, three, and two or fewer years of high school mathematics. The young women who had taken advanced high school mathematics were more frequently than other young women able to recall a pleasant first experience with mathematics. They were also more ambivalent about being smart. More of them felt uneasy with boys because of their smartness, and they were more likely to say that they "play dumb" than the female students who stopped with just three years of mathematics. It is Sherman's opinion that it is not anxiety, dysfunctional attitudes, or lack of ability that keeps women from mathematics. Instead, she believes that it is a network of sex-role influences that makes mathematics, and the careers associated with mathematics, appear incongruent with the female role.

iii) Emotion: The new research on the role of emotion in problem solving, and specifically in learning mathematics, has seldom focused on gender. McLeod (1989b) lays out an agenda for research, much of which he and his colleagues are carrying out with college students. The research uses verbal reports of emotion as well as methods of assessing body movement, facial expression, changes in posture, and other indicators of emotion. Students are asked to solve various kinds of problems while these researchers attempt to study the magnitude and direction of emotion, its duration, and the student's level of awareness and control of emotion. The goal of this work is to clarify how these factors promote and inhibit effective problem solving in non-routine problems and to see how they interact with different types of cognitive processes, instructional environments, and beliefs that students hold. Although gender is not yet a major theme in this work, or that of Buxton (198l), Marshall (1989), or Lester and his colleagues (1989), McLeod (1989b) suggests that current research on emotion in problem solving has "particular relevance for women and minorities, groups that have been underrepresented in mathematical careers."

In summary, the research assessing affective factors finds some evidence that men and women hold different beliefs about mathematics but that women students are not as negative in their attitudes about mathematics and science as would be expected from their lower enrollments in higher-level courses and in majors that require mathematics. Certainly, this research does not support the view that women turn away from mathematics and science because of negative attitudes and distaste for these fields. Their views that mathematics and science conflict with their concepts of their gender roles appears far more influential than gender differences in the affective domain. The new research on emotion may find greater evidence of gender-specific emotional inhibitors in problem solving, but if past research on affective factors is a guide, that seems unlikely. Instead, this new research will probably show that negative emotions constrain the problem solving of women and men in much the same way.

Personality: The classic work of Roe (1961) on the personality profile of creative scientists set the stage for many subsequent personality studies of men and women scientists. Roe stressed that creative scientists are independent, tolerate ambiguity but put an end to it in their own way, take risks, and are more involved with things and ideas than with people. Studies done in the 1970s support Roe's emphasis on independence. Helson (197l) found, for example, that independence (as measured by the California Personality Inventory) differentiated women mathematicians who were judged by their peers as especially creative from those judged as less creative. The creative women mathematicians also scored higher on measures of introversion and intellectual flexibility. Handley and Hickson (1978) also used personality measures to distinguish among female mathematicians, although in this study the women were at a much earlier stage in their careers. These researchers studied 128 college seniors who had earned at least a strong minor in mathematics from a southern university. The students were divided into two groups: those who planned to go into teaching and those who had non-teaching careers in mind. The non-teachers were more independent and creative as measured by the Cattell Sixteen Factor Questionnaire.

A more recent study supports the role of certain personality traits in accounting for success among women interested in science (DeBoer, 1985). In this study 118 college students who had taken at least one science course in their first year at a liberal arts college were administered the Omnibus Personality Inventory and the Personal Values Inventory. Women were 45 percent of this group of students. Overall, the men and women did not differ on the personality measures, but three of the six measures did correlate with women's judgments of success in science. Women who felt that they had been the most successful were shown by these personality measures to be the most hardworking and persistent, the most likely to be oriented to the future, and least likely to be reckless in the sense of taking physical risks and of seeking thrills. None of the personality measures correlated with the men's judgments of their success in their first science course(s).

These studies suggest that while personality does not distinguish men from women who take science courses and go into science and mathematics careers, there is a personality factor that influences women who feel themselves to be the most successful, pursue non-teaching careers using their mathematics training, and are judged by others to be the most creative.

Causal Attributions: Currently much more research is devoted to the impact on mathematics and science achievement of causal attributions than of personality traits. The greater attention given to cognitive issues reflects the preoccupation of psychologists with cognition in the past fifteen years. It is not surprising that studies of individual predictors of success in science and mathematics would also emphasize cognitive issues.

A series of studies conducted in the early to mid-1970s developed a picture of distinctive male and female patterns of causal attributions. It was found that women tend to attribute their successes to external factors (such as luck or task difficulty) and their failures to internal factors (such as lack of ability or effort), while men tend to show the opposite pattern (Frieze, Whitley, Hanusa, and McHugh, 1982; Simon and Feather, 1973; Nicholls, 1975). There is also some evidence that women attribute their successes to unstable factors and their failures to stable ones (Frieze, Fisher, Hanusa, McHugh and Valle, 1976). It is important to note, however, that these gender differences in attributional style are small though statistically reliable.

A recent small-scaled study of college students who dropped their original intentions of majoring in chemistry or mathematics (McDade, 1988) supports a gendered pattern of causal attributions for success and failure. While women were only slightly more likely than men to drop their science aspirations, the reasons for switching to other fields were quite different for men and women. The women described the attrition process in personalized and self-blaming ways. They specifically emphasized their own shortcomings and feelings of incompetence and disappointment with themselves. The men who left these majors described the attrition process as an externalized experience. They talked of wanting to pursue better opportunities for developing their interests and improving their intellectual and material well-being; and they wished to match their work goals more closely with their overall life goals.

A cross-cultural study of attributions involving men and women in five nations (India, Japan, South Africa, the United States, and Yugoslavia) confirms some aspects of this now well-known gender-linked pattern. Women attributed their failures significantly more than men to internal factors in all five nations, but the authors (Chandler et al, 1983) point out that these gender differences are very small and, particularly in India, there are many more similarities than differences between men and women.

In summary, this research shows that while there are some reliable gender differences in causal attributions, these differences are not large--certainly not large enough to account for the behavioral differences in choice, retention, and the greater achievement of men than women in mathematics and science.

Environmental Factors

Many studies of environmental factors have focused on classroom dynamics and, in particular, on possible differences in the interactions between teachers and male and female students; differences in the responses of male and female students to teaching style, competition between students, and to classroom climate; and differences in the social support given to male and female students. Very often these studies have depended on the self-reports of students rather than on observational methods that would document verbal and nonverbal behaviors within the classroom. Our review of this research will highlight the factors that, on the basis of student reports, seem promising enough to warrant other observational studies.

Teacher-Student Interactions: There has been considerable discussion in the field of education concerning the interactions between students and their instructors. Much of it has suggested that women students tend to have fewer interactions with teachers, and that these interactions tend to be less encouraging than those between teachers and their male students. Additionally, it has been suggested that women students are shortchanged in terms of being acknowledged by teachers; that is, they are not called upon as frequently as the male students; their responses are not as frequently expanded or elaborated on by teachers; and fewer questions are asked of them by instructors. Teacher bias against female students in favor of male students is believed to extend beyond the classroom as well. Women students are believed to have fewer interactions, both of an academic and an informal nature, with teachers outside of the classroom. At the college level, this lack of contact outside the classroom is believed to have negative consequences for women students by excluding them from receiving important information related to department, academic culture and research possibilities.

In spite of the various speculations about the potential impact of teacher-student interactions, relatively little careful research has been done on gender dynamics in college classrooms or on the nature of these interactions outside of the classroom. Even fewer studies have been done specifically of physical science and mathematics classes.

More research has been conducted in high schools. Using observational techniques to assess the climate of the classroom, Becker (1981) explored the differential treatment of males and females in high school mathematics classes. The results support the prevalent idea that women are being shortchanged in the classroom. In a set of 10 high school geometry classes, she found that teachers responded more to, asked more questions of, and initiated more nonacademic contact with male than female students. In fact, the male students received 70 percent of the contacts interpreted as encouraging academic abilities. (Since seven of the ten teachers were women, these results did not occur because of a male bias against female students.)

A study of college students carried out by Hearn and Olzak (1981) does not find evidence of differential treatment, however. This study did not analyze teacher-student interaction specifically in mathematics and the sciences, nor did it go beyond the self-reports of students. Questionnaires were administered to 346 seniors at a large university. The males and females did not report much difference in the interactions that they had with teachers during their college years.

Gender dynamics in classrooms may be affected by very subtle factors that would not be captured in questionnaire studies. Something seemingly as simple as the instructor not knowing as many of the names of the females as the males can affect the overall classroom climate. There is some evidence that students at least believe that instructors more often learn the names of male than female students. In their study of 941 graduate and undergraduate students at a midwestern university sampled from 102 intact classes that had been allocated proportionately according to department (natural science, humanities, social sciences, business, and education), Schnellman and Gibbons (1984) found that more males than females believed that the instructors knew them. More men than women students said that they talked with their instructors outside of class, went to see the instructor for help when needed, and felt comfortable going to the instructor's office outside of the officially listed office hours. Schnellman and Gibbons connect these phenomena by suggesting that students are more likely to seek out professors and participate in class when they feel that the professor knows their names.

Studies of women majoring in different fields further suggest that women in science have more negative classroom experiences than women in other fields. In a study of women students who were qualified to do science based on their quantitative SAT scores, 36 percent of the women in science, but only 14 percent of those in other fields, recalled having had a personal discriminatory experience in their classes at the University of Michigan (Manis, Thomas, Sloat, and Davis, 1989). Examples included students feeling that the professor put women down, patronized women, or ignored them; that the professor did not take women seriously, did not respect their ability, or in some way conveyed that women were less able than the men intellectually. Manis et al. (1989) suggest, however, that the effects of these experiences on women vary a good deal. Some women feel challenged by such biased attitudes and seek to "prove" that they are competent. Other women report that the negative attitudes of their instructors dampen their self-confidence and make them question whether they should remain in the sciences and mathematics.

Teaching Style: The manner in which the physical sciences, mathematics, and engineering are taught may contribute in part to the chilliness that many women (and some men) feel in the classroom. Keith (1988) argues that the mode of delivery in mathematics classrooms is a negative factor for many students, and perhaps more for women than for men. She describes the typical teaching style as an "advocacy mode"--one in which the teacher conveys the important information and does not foster interaction among students. On the contrary, she argues, an atmosphere is created in which students compete against each other. Keith believes that more students would continue in mathematics if teachers would utilize a "response mode" of teaching--one that allows students to ask questions, interact with each other, and engage in problem solving together. She suggests these changes within the context of changing the curriculum in college departments.

Criticisms of the teaching style in science and mathematics courses figured heavily in the decision not to continue in these fields by a group of women college students at the University of Michigan (Manis, Thomas, Sloat, and Davis, 1989). Questionnaires were given to students who expressed an interest in science when they first came to college and later dropped out. These students cited the following factors: poorly taught courses; communication difficulties between many TAs and students; insufficient personal interest in students on the part of professors; and badly organized courses.

In Tobias' (1990) unique "second tier" project, a small sample of postgraduates who had demonstrated ability in other fields while avoiding science in college were recruited to "seriously audit" an introductory undergraduate course in physics or chemistry. The goal of the project was for the auditors to study and help clarify the process and problems believed to be linked to the learning of science. Although the auditors felt that the science courses elected were taught adequately enough, they also felt that the courses were not taught in such a way as to "woo" them to seriously consider science as a field of study.

The teaching of mathematics and science does not have to discourage students. Some teachers do an excellent job of motivating and holding the interest of their students, and, in particular, of encouraging females to continue taking science courses and pursuing science careers. In a 1983 nationwide project studying teachers who were successful in promoting these goals for precollege-age girls, Kahle (1985b) identified several positive teaching behaviors and institutional strategies: use of nonsexist language (particularly when giving examples in lectures or in demonstrations); including information on women scientists; and avoiding gender-stereotyped views of science and scientists.

Competitive and Cooperative Learning Environments: The degree of competition within the classroom has been cited by numerous women students as negatively affecting the climate in mathematics and science classrooms. Competition may be derived from many different classroom procedures: grading practices, oral quizzes, team competitions, daily or weekly prizes, "ability" grouping, and so on. Studies often fail, however, to specify exactly what students mean when they criticize the "competitive atmosphere".

Peterson and Fennema (1985) demonstrated in a study of 36 fourth grade mathematics classes that the nature of mathematics activities had differential effects on the achievement of boys and girls. For girls, a mathematical activity that was competitive in nature was negatively related to achievement. They performed better when the activity required students to cooperate with each other. The reverse was true for boys. They performed better in competitive activities. Unfortunately for girls, most mathematics and science classrooms use many competitive tasks.

The special auditors in the Tobias project (1990) found their science courses to have a heightened sense of competition as well as a lack of community among the students. These factors contributed to feelings of wanting to abandon science for the second time around.

The issue of competition continues at the college level. In recalling their first-year experiences, women students at the University of Michigan were more likely than men students (24% v 11%) to say that they disliked the competitive atmosphere in classes, and male and female students agreed that competition is a serious problem in science classes. Forty-five percent agreed with the complaint that students in science classes are too aggressive and competitive (Manis, Thomas, Sloat, and Davis, 1989). In rating factors that might discourage women from pursuing careers in science, 35% of the women (both science and non-science majors) believed the aggressive and competitive attitudes of students in science classes to be a serious problem. Roughly only a fifth of the men felt so. More than a third of the women students in other fields (and close to a third of women science majors) indicated that competition was a serious problem for them, whereas only 19% of men in other fields and 18 % of men in science fields felt that competition was a serious problem for them.

Chilly Climate: The concept of a chilly climate for women students has become one of the most frequently heard buzzwords on campuses. Unfortunately, the definition of what constitutes a chilly climate varies widely among researchers and administrators. One definition of climate makes it so broad as to include the entire social psychological context within which teachers and students interact and form relationships (Rosenfeld and Jarrad, 1985). The elements of the climate are so subtle that it becomes a challenge to researchers to assess them. To date, most surveys have had to rely largely on the subjective interpretation of the students.

Massachusetts Institute of Technology female graduate students and research staff provide such comments about the research environment in the computer science department. They talk about feeling neglected and invisible (Barriers to Equality in Academia, 1983). Women students at the Universities of Connecticut and Michigan express similar feelings about their treatment in college classrooms (Mellow and Goldsmith, 1988; Manis et al., 1989). And Clark (1990) reports that women students at Princeton University describe feeling marginalized and isolated. They are more likely than men to feel that they do not fit comfortably within the campus climate and that they are not as accepted and supported at the university.

Part of what makes it difficult to assess what this chilly climate comes from or means to the students is that the behaviors women mention seem subtle, frequent, and yet ordinary. Schnellman and Gibbons (1984) call them "microinequities" -- the small and subtle discriminatory and/or derogatory behaviors exhibited by faculty and others in the institution that undermine an individual's sense of confidence. The critical question is whether or not women are subjected to these subtle behaviors more than men. Hall and Sandler (1984) argue that they are, and that inequitable attitudes and behaviors contribute to a particularly chilly campus environment for women. The anecdotal evidence that has been gathered in interview and focus group studies of women support this assertion, although our review of the literature does not reveal careful, systematic studies that demonstrate through observations what this chilly climate actually is and what behaviors project it to women students.

To summarize, it appears clear that women students often have a subjectively different experience within the classroom, resulting in a heightened sense of discomfort, negligence, and/or discrimination. However, relatively little is known of the short-term as well as long-term impact of the experience of these "microinequities" on young women's achievement, career goals, decision-making, and choice of field of study.

Social Support: Another feature of the environment that may affect men and women students differently is extensiveness of social support for studying science and math. Counseling and advising are obvious aspects of social support. It is assumed that the counselor is a key in encouraging or discouraging young women in the decision to enter and stay in science, math, and engineering. Eccles and Hoffman (1984) note, however, that most studies show that school counselors play a very small role in influencing the career decisions of students (see also Armstrong and Price, 1982). Of course, the fact that counselors are not cited as influential by students currently does not mean that they could not be important if school systems wanted to encourage more female students to consider mathematics and science. The roles that school counselors play can be distinguished from the counseling role that teachers can and do play in the career decision-making process for women.

The literature we have reviewed does support the importance of teachers who can and do play a powerful role in shaping the aspirations of students (Casserly, 1983; Erickson, 1987). Previous research is not so clear, however, in detailing exactly how teachers influence students or in delineating how big their influence is relative to that of other people, such as parents and other adults. Nor is the research that has been carried out to determine how teachers affect the specific decision to major in math, engineering, or science completely consistent. In a study of 113 college women in two separate colleges in the northeastern United States (Fitzgerald and Silverman, 1989), science majors were more likely than other majors to report a strong positive influence on their choice of major from their high school teachers. These findings suggest that for women contemplating a science or engineering field in college, early and positive influence from teachers in secondary schools is important.

Another study (Hackett, Esposito, and O'Halloran, 1989) of 180 graduating senior women at a small western women's liberal arts college shows that the teacher's influence is related to a number of career outcomes. Women students who say that a female teacher was influential in their college years were more likely than other women students to go into science-related fields. In contrast, women who mentioned a male teacher as being influential were less likely to pursue a science-related major. The positive impact of a female teacher taking an interest in women students is also reported by Stake and Noonan (1985). These authors found an appreciable improvement in the confidence and motivation of women students who mentioned a female teacher as their most important model in the college environment. This finding was also replicated in an earlier study conducted by one of these authors using a sample of high school students (Stake and Granger, 1978).

The influence of like-sexed models is noted for both genders by Basow and Howe (1980). Female college seniors were significantly more affected by their female teachers than male teachers in career-decision making. Likewise, male students felt that they were more influenced by male teachers.

The role of parents in the decisions women make for field of study and career has generally been acknowledged as strong. Support from family varies, however, as a function of the particular field and career path women choose to follow. Fitzpatrick and Silverman (1989) found that parents' support of daughters' career choices was stronger for nontraditional fields, such as engineering, than for more traditional areas, such as the humanities and social sciences.

There is evidence in the literature that the support offered by mothers may differ from that offered by fathers. The most consistent finding is that mothers seem to have greater importance than fathers in the choices daughters make. One study, conducted by Hackett et al. (1989), suggests that the influence of the two parents may be contradictory. In this study graduating senior women felt that their mothers had exercised a positive influence on their career-choices, while the influence of their fathers was negative. The authors suggest that the fathers' negative influence may reflect their discouragement and/or dislike of their daughter's acting "out of role" by choosing a nontraditional or science-related college major.

The impact of same-sex and opposite-sex friends on the decision of women to enter and remain in nontraditional areas has been underemphasized in studies of women's choices. Friends carry significant weight in attracting women into nontraditional areas of study as well as keeping them there. Fox et al. (1980) found that females are more likely to make a nontraditional career choice and to remain in a nontraditional job or program if there are a reasonable number of other females present as classmates and/or as colleagues. Lunneborg and Lunneborg (1985) further demonstrate that peers are a greater source of support and encouragement for nontraditional, professional women than for women with more traditional aspirations.

A few studies have asked if the gender of the friend matters in the choices that women make. Basow and Howe (1980) conclude that female students are equally influenced by friends of both sexes, while male students are more influenced by male friends. The influence of male and female friends can be both positive and negative (Hackett et al., 1989).

These studies of social support demonstrate that women (and men) are making choices within a web of important social influences. Parents, teachers, and friends figure prominently in this web, while people who have been trained as professionals in giving students academic and career counseling seem much less important. The role of peers in particular needs to be understood more fully. More research should be done to clarify the way in which friends shape the choices that women make to go into or avoid nontraditional fields such as science and mathematics.

<u>Internships</u>: In recent years, considerable emphasis has been put on the role that research internships may play in helping students form career commitments. The assessment of the National Science Foundation's Research Experiences for Undergraduates (REU) program (NSF, 1990), as well as other smaller studies, suggest that research experience can be a key factor in encouraging the more uncertain students as well as bolstering the more confident students towards the fields of science and mathematics.

Brown (1989) stresses the importance of "research apprenticeships" for young women at Case Western Reserve University going into theoretical and industrial physics. Although Brown does not present a formal evaluation of the apprenticeship program, he does cite several benefits of participation. The women apprentices earn money, improve communication skills, experience working as a research scientist, receive credentials for future employment and/or graduate school, and develop stronger confidence in their choices. Brown emphasizes the program's impact in building confidence, especially for women who are uncertain about their capabilities and choices.

In a national sample of 5,162 college students, Pascarella and Staver (1985) found that on-campus work in science had a direct effect on the science career choices of both males and females. The opportunity to engage in research while in college had consistent, although not extremely large, effects for both genders. Students were more likely to continue in science and mathematics fields if they had the opportunity to work in science labs and other research settings.

The most comprehensive evaluation of research experiences of undergraduates was conducted by the National Science Foundation (1990). The Foundation's report notes that two types of students should be considered in reviewing the results of the assessment of research internships. The first type can be characterized as deeply interested in a particular field and eager to do research in it. The second type also has a definite interest in science and mathematics but in general is less certain about pursuing graduate study and working in a science or mathematics field. The two types of students come to the research internship with different educational and career aspirations, as well as with different expectations about going to graduate school and about other issues related to their academic and career futures.

The impact of the Foundation's REU program was examined after three years of implementation. The program was most effective in helping the more uncertain students clarify and become more sure of going on to graduate school in the sciences and mathematics and of choosing a particular field of specialization. For the more highly committed students, research internships had less dramatic impact and primarily bolstered the students' original plans.

Overall, the program appeared to influence students' expectations of attaining advanced degrees. The percentage of students who anticipated acquiring an advanced degree rose from 75 to 92 percent after participating in the program. Eighty percent of the students indicated a heightened interest in science and engineering as a result of their REU participation. Males were far more likely to choose the fields of engineering, physics, and computer sciences, while females were more likely to choose a biological or social science majors. No marked gender differences emerged for the field of mathematics.

Gender differences were also found in the reasons students gave for their decisions to participate in the REU program, although gender was a factor primarily among the less certain students. In this group, women were more likely than men to say that an interest in science or engineering in general, being a researcher, being in a particular research field, and wanting to pursue graduate study in science or engineering were very important in their decision to take part in the program. These women students approached the REU as an opportunity to find out if science or engineering were fields that would interest them. Men who were not very certain about their career choices gave somewhat different reasons for participation. They were more likely to indicate that "wanting to know" about science or engineering played a relatively minor role in their decision to participate in the REU program. No gender differences were found for the more committed students in their decision to participate--being strongly attracted to the field of interest and wanting to do real work in that field were rated as either "important" or "very important" in deciding to participate.

Multiple Factors: Causal Models

Most of the research discussed previously has focused on single factors such as self-concept or classroom dynamics. Usually, the two types of factors have not been examined together to determine their relative, predictive value on mathematics and science choices and achievement. The integrationist view suggests that multiple factors must be considered since it is clear that gender differences do not come merely from individual or from environmental factors.

A few studies that take both types of factors into account have been done. Using path analytic techniques, these studies present a model of how these various factors are related to one another and which factors can be considered causally prior to others. Generally the goal is to delineate the relative importance of individual and environmental factors in accounting for the choices and achievements of males and females.

As most of the research on gender differences in mathematics and science achievement has been carried out at the elementary and high school levels, the models of multiple causation are more comprehensive at these levels. The research done at the college level is still sparse, although it does allow for some inferences to be drawn.

Lips and Temple (1990) looked at intent to major in computer science among college students and found different significant predictors of enjoyment of computer science courses for women than for men and therefore different factors contributing to majoring in computer science. For males, mathematics confidence was the strongest predictor, followed by interest and enjoyment of computers, confidence with computers, and amount of computer experience. For females, experience with computers was the most important predictor of interest in computers. The authors suggest that men feel more comfortable in male-dominated computer classes, while women need more computer experience so as not to feel isolated and uncomfortable in these classes.

Ware, Steckler and Lesserman (1985), using a longitudinal dataset, examined why undergraduates who enter college intending to major in science abandon their plans before they are required to declare a major. Holding ability scores constant, they found that responses differed for men and women. For women at the end of their first year courses, maintaining an interest in science and choosing it as a major was predicted by: family background (highly educated parents); aptitude for mathematics (outstanding SAT-M); strong desire for prestige, control, and social influence; and affiliation. For men, having high grades in the first year science courses and being unusually certain about the major before entering college were the most important predictors of continued commitment to science. These authors did not test for the students' self-confidence in mathematics and science, but relied on the concept of self-confidence in interpreting their results. Since only women of extraordinary mathematics ability continued to pursue a science major, while men of varying abilities did so, they note that the "need to prove oneself through superior performance may also be explained as a reaction to self-doubt." Their recommendations to offset this reaction include a networking community, and encouragement and reassurance from professors and counselors, which the authors argue can "tip the balance of indecision for a hesitant student by strengthening her confidence in her ability."

Hackett (1985) also found that self-confidence was a critical issue, although it was critical for both women and men. In a study of 117 college men and women, mathematics self-efficacy (a form of self-confidence) and mathematics anxiety were the most important predictors of choice of college major.

Ethington (1987) also looked at intended majors but only among college women. In this study of 314 women, special emphasis was placed on majors in quantitative fields. Self-ratings of math/science ability (a measure of confidence) were the most influential variables in a model that included years of mathematics, years of science, number of advanced courses, extracurricular activities, mathematics grades, science grades, and leadership self-concept.

Sense of competence in science ability was found to be an important explanatory factor for choice of career, and particularly for choice of a science career among women studied by DeBoer (1984a). This study of 302 students included both men and women. Women performed as well as or better than men in their high school science courses but, once in college, women took fewer science courses and no longer performed better than the men. Sense of competence directly affected choice of a science major and a science career, and was in turn affected by number of high school science courses, grades in those courses, and gender. The author speculates that the devaluation of women's performance both by men and by other women, even when the performance of women is substantially the same as that of men, leads women to form a derogatory opinion of their competence in science. DeBoer suggests that as a means of encouragement, science educators give high school and college women the recognition they deserve for their academic performance.

In the research on elementary and high school students, two complex and refined models of multiple causation stand out. One, the Fennema and

Peterson Autonomous Learning Behavior model, is based on conclusions from the research literature, but it has not yet been tested empirically. The second, the Eccles Expectancy-Value model, has been empirically tested.

The Fennema and Peterson (1985) model hypothesizes that gender-related differences in mathematics achievement are a direct result of autonomous learning behaviors, such as working independently on high-level tasks, persisting at such tasks, choosing to do these tasks, and achieving success in them. These behaviors in turn are directly influenced by internal motivational beliefs and by external, societal factors, such as family, media, peers, and classroom dynamics. The authors submit that among internal motivational beliefs, several interrelated factors seem important High among them are confidence in one's ability, perceived usefulness of course material, and attributional style. Gender-related differences exist in all three factors. The authors argue, however, that the most important influence is the congruency between sex-role identity and achievement in mathematics, and that sex-role identity mediates between these motivational states and cognitive functioning.

Eccles (1983, 1987, 1989) uses elementary and high school research to form a comprehensive model that is also now tested with data she and her colleagues have collected. Her results show that there are two proximate or direct causes of intention to take more math: the student's self-concept of mathematics ability (what she calls expectancy and is a form of self-confidence), and the student's valuation of math. Eccles places the role of self-confidence in perspective. Confidence is directly affected by the students' perceptions of their socializers' perceptions of their mathematics abilities, by their parents' aspirations for them, and by task difficulty. These variables in turn are directly affected by yet other socialization variables.

Eccles stresses the fact that the student's valuation of mathematics is actually somewhat more strongly related than confidence to intention to enroll in math. Her model assigns the central role to valuation of tasks. She argues that males and females have different but equally important goals and valuations of tasks. Although science is valued in our society and more men than women become scientists, this should not lead to the conclusion that women's goals are deficient; they are merely different from those of men. Women's choices must be legitimized as "valuable on their own terms rather than as a reflection or distortion of male choices and male values." She suggests specific interventions that stress "rational and comprehensive career counseling, changing opportunity structures and classroom experiences across the lifetime, providing societal supports for parenting and personal development rather than motivational retraining, and macro-level reassessment of the differential payoff afforded to male versus female occupations."

E. Interventions

A variety of interventions have been employed on college campuses aimed at recruiting and retaining women students in nontraditional fields of study. In this section, several of these interventions will be outlined as well as a discussion of several noted programs.

Summer Outreach/Transitions

Several single interventions or programs have aimed specifically to either introduce women students to the physical sciences, mathematics, and engineering as potential fields to pursue advanced study, or to assist women in making the transition to the above mentioned fields. Part of the problem in reviewing the various interventions has been that a considerable number of these interventions are focused on recruiting more women into the field of engineering. Additionally, the majority of such programs are designed and executed for a specific target population, often young girls who are of middle or high-school age, such as the Douglass Science Institute for High School women (Rutgers University), Summer Science program for 8th-grade girls (University of Michigan) or the Talented Youth Mathematics program (University of Minnesota). Relatively few summer programs have been designed for college-age women in these areas of study.

An exception is a program at Southern Illinois University at Carbondale. SIU sponsors a 10-day on-campus bridge program for incoming female students. It is designed to ease the transition for these women students by offering "highlights" of a calculus class as well as discussions focusing on how to succeed in future math classes.

Curriculum Development

Various ideas and methods have been implemented in the curriculum of the physical sciences, mathematics, and engineering with the intention of easing the transition and/or creating a more conducive environment for women to succeed in these fields. One widespread intervention has been to offer a dual-degree option in liberal arts and a nontraditional field. A liberal arts and engineering dual-degree option is available at several women's colleges. These dual degrees encourage students to have a more broad-based undergraduate education, which many believe to be especially important for women students who are not completely sure about their interests in science.

The University of California (Berkeley) has offered other curriculum-based interventions including tutorials, innovative courses, and math-based workshops to encourage women students in nontraditional areas of study. Mills, a traditional women's college, has implemented several interventions aimed at creating a more relevant and interesting curriculum in the nontraditional areas for women such as offering a precalculus course (to strengthen one's skills before taking calculus) as well as interdisciplinary courses with an emphasis on applications.

Public Relations

A more traditional means of reaching and encouraging young women for the nontraditional fields of study has involved using some means of public relations. Typically, this form of outreach has consisted of sending recruitment/information materials to high school teachers, counselors, and/or parents. Posters, brochures, and/or advertisements have been the more common means of representing the various college or university programs interested in recruitment. For the most part, this type of outreach has been targeted towards young women still in middle and secondary school.

Several approaches have been taken to interest women students who are not yet decided on a science major. For example, Pennsylvania State University highlights their engineering program for women not only on the bulletin board near the engineering library (presumably for women already in the field) but also in college and university publications. Also an advertisement about the program is placed in the campus newsletter during women's history month.

Various career days and receptions are planned for women to introduce them to engineering, mathematics, or a field in the physical sciences. Young women who are pre-college as well as college age are invited to participate in these orientations in hopes of recruiting them into the respective fields. At Nashville State, for example, receptions are held for the educators of women in engineering and engineering technology, as well as for the young women themselves.

Mentoring

The value of having an individual (an advanced graduate student and/or a faculty member) take a special interest in the nurturing of the intellectual and professional potential of a student cannot be underestimated. Having a mentor is believed to be even more critical for women students, who, due to their lack of numbers, perceive themselves as minorities in the departments of physical sciences, some fields of mathematics, and engineering. Throughout this report we have seen the importance women students attribute to encouragement and to being taken seriously by faculty.

Several universities and colleges have recognized the value of mentoring and have incorporated various aspects within their overall programs or as a single intervention. The University of Washington ("Big Sisters") and the Rutgers-Douglass program ("Big Sister/Little Sister") have instituted similar programs aimed at coupling the newer undergraduate female student with an older, more experienced advanced undergraduate/graduate female student with the intention of developing a mentoring relationship. Other universities have developed mentoring programs for students with faculty members (University of California-Berkeley) or by matching professionals with students (the "Mentoring Program" at the University of Washington).

In addition to utilizing the talents and expertise of faculty or professionals active in the field as mentors for young women, several universities have focused on peers as mentors (Alverno College, Wisconsin) or alumnae (Wheaton College, Massachusetts).

Professional and Social Support

Women (both students and professionals) in nontraditional fields often feel ignorant, isolated, and/or rejected from the traditionally male-exclusive social networks in these fields. These social networks are believed to be important in that the exchange of information and resources among the members can provide certain advantages or privileges.

Rutgers University/Douglass College has a unique and comprehensive program aimed at not only attracting women into nontraditional fields but also sustaining and nurturing them along the way. In addition to providing a special residence hall for undergraduate women in these fields, Rutgers also supports the women with peer study groups and peer tutoring. Living in an environment with others who share similar interests can be both positively reinforcing as well as an avenue to needed information (e.g. courses, requirements, study strategies.)

Other interventions aimed at supporting women in nontraditional areas include planning "social" gatherings or orientations at which women with similar goals and interests can meet and see others like themselves. Several universities have compiled directories of women in respective fields (University of Washington), of local women in the physical sciences and mathematics (University of Michigan Center for the Education of Women), or maintain current files on campus/national organizations concerning women in these fields as a source of support for emerging women professionals.

Evaluation

Intervention programs have not been accompanied by any long-term studies of effect. Very few programs use random assignment so that effect could be reliably assessed. And the intervention programs are not comprehensive in their scope in addressing the problems of recruitment and retention.

IV. UNIVERSITY OF MICHIGAN STUDIES

A. Introduction

If the pool of U.S. mathematicians and physicists is to be enlarged, research universities must play a central role. Yet few studies have examined the experience of mathematics and physics undergraduate and graduate students in major research universities. Moreover, little is known about factors which have a particular effect on the experience of women students in these fields.

In order to address this knowledge gap, three studies were conducted at the University of Michigan under the auspices of the Sloan Project. Each of these studies explored students' perceptions and the factors which contributed to student persistence or attrition.

The first of the three studies surveyed students who were enrolled in first semester Honors mathematics courses during the Fall Terms of 1987 or 1988. Students enrolled in these classes represent some of the best prepared incoming students and are a potential pool of mathematics science concentrators. The study documents a high "dropout" rate in terms of continuing mathematics enrollments. Gender differences revealed by the study appear to be based on differences in perception, not in ability.

The second study used survey methods to examine the experiences of students who graduated with majors in mathematics and physics in 1990. While this study revealed few gender differences, the differences which did emerge were consistent with those identified in the study of Honors mathematics enrollees and in the larger body of research literature. Even among those who completed mathematics and physics majors, women were less likely to find encouragement in their departments, less likely to find professors to take a special interest in them, and had slightly lower self confidence than their male counterparts.

The third study involved two focus groups of women graduate students in mathematics and physics. Several themes emerged from the qualitative analysis of the focus group content that were again consistent with the literature and the data from the two Michigan surveys. Among them, encouragement from faculty and parents played a key role in the women's undergraduate experience and their decision to persist in their studies. Some of the themes that surfaced may be gender-free and more specific to graduate students as a whole. In retrospect, we regret that we were unable to have focus groups of the male mathematics and physics students to learn their responses.

B. First Year Honors Mathematics Students

Introduction

The Honors mathematics sequences at the University of Michigan are designed for entering first year students with a particularly strong background and stated interest in mathematics. Almost all of the Honors mathematics students come from the General Honors Program (during the years represented by our survey, 90% of the Honors mathematics students were also in the General Honors Program), but the courses are open to all qualified students..

The honors mathematics concentration program includes four basic courses (linear algebra, modern algebra, analysis, geometry/topology), four elective courses, and a cognate. Students intending an honors concentration in mathematics also take a two-term honors calculus sequence in both the freshman and sophomore years. The calculus courses involve substantially more theoretical work than the standard calculus courses (where problem-solving is emphasized over theoretical and conceptual understanding).

Nearly half of the students in our survey entered the University intending to concentrate in the natural sciences (either the physical or life sciences), and a similar percentage were actually involved in a science concentration at the time of our survey. While the students who enroll in the Honors mathematics courses are under no obligation to pursue an academic career in the natural sciences or in mathematics, they represent some of the best prepared incoming students at the University and certainly provide a pool of potential mathematics-science concentrators. Because of their academic accomplishments and talents, these students are a particularly important group for investigation: What are the experiences and subsequent plans of these students, and most importantly, do these experiences and plans differ along gender lines?

Tables 1 through 9 summarize the result of our analyses. While we included no separate course grades or mathematics ability measures in our data, general measures of academic achievement suggested a high degree of comparability between the male and female students. There were no significant differences between their incoming high school grades nor between their college grades within their ultimate areas of concentration. The female students possessed slightly higher overall grade point averages. Although we cannot dismiss the possibility of grade differences in their mathematics courses, the gender differences in experience and choice revealed in our study appear to be based more on **differences of perception** rather than **differences of ability**.

In general, we witnessed a very high rate of discontinuance among the first year Honors mathematics students; only 15% of the students, male and female alike, completed the honors sequence. The majority of the females (58%) dropped out of an Honors mathematics sequence and elected no further mathematics courses, while the majority of males (54%) dropped out of Honors mathematics and elected non-Honors mathematics. Students offer various reasons for dropping out of the honors sequence with the majority citing the material as unnecessary for their studies.

Certain motivational differences for dropping out of Honors mathematics were also apparent. While more than half of all students felt the material to be unnecessary, the male students cited two additional external factors with greater frequency: heavy course load and "outside factors." The female students cited a lower level of interest in the subject matter.

The overall attrition rate may be partially explained by the ultimate concentration decisions (less than half of all students went on to major in the sciences). The aforementioned gender difference concerning the decision to continue with non-Honors mathematics courses can be partially explained by the differences in choice of a specific science field. Female science concentrators were more likely to be in the life sciences (requiring less mathematics), while the male science concentrators were more likely to be in mathematics or the physical sciences.

Finally, female students tended to feel the benefits of cooperative environments and the detriments of competitive environments more so than their male peers.

Description of Sample

We obtained the list of all students who enrolled in either of the two first semester first year Honors mathematics courses during the fall of 1987 and 1988 (a total of 174 students), capturing two years worth of incoming undergraduates. By the end of the formal survey period in the winter semester 1991, during which time we contacted respondents by phone, 148 out of the original 174 students had completed our survey (85%). The remaining 26 were excluded from further analysis as the respondents were unreachable (either because the student had no available phone number, was out of the country for the current semester, had transferred away from the University, or refused to take part in the survey).

Table 1 includes a description of the final sample: 27% of the entering Honors mathematics students were females (40 out of the 148). All subsequent analyses were computed separately for males and females, significant differences indicated by the resulting chi-square or t-test statistics.

Four-fifths of these students were white, and the remaining fifth was predominantly Asian; nearly all were in their junior or senior year at the University. Nearly 80% of all students, male and female, were enrolled in the Mathematics 185 course, the intermediate level Honors course. The remaining 20% were enrolled in Mathematics 195, the advanced Honors course.

The First Year Honors Mathematics Experience

Even before classroom experiences begin, students may feel a differential treatment in the selection process. Admission to the Honors mathematics courses almost always includes discussion with one or more Honors counselors. While students are free to choose their academic schedules, counselors often encourage or discourage the election of certain courses depending upon the background and expressed interests of the student. Table 2 describes the memories of the students' discussions with the counselors. Although there is no statistically significant finding, a moderate trend is suggested. Very few students of either gender remember being discouraged from electing an Honors mathematics class (less than 10% in either case), an indication of the influence of the academic counselors. Males felt they were mostly encouraged (73%) and a majority of females were also encouraged (58%), but other women remembered a more neutral experience where neither encouragement nor discouragement was present (37%). Even in the absence of any evidence supporting actual differences in the counseling experience, there is nonetheless a suggestion of **differences in perception.**

Students were asked to rate the frequency of several activities in their mathematics classes (on a scale from 1=often to 4=never). Table 3 summarizes these responses with mean scores on each item. A mean score near 1 indicates a regularly occurring activity, while higher mean scores reflect less frequent activities.

Of the thirteen activities, only two displayed significant gender differences: the frequency of tutoring, and the feeling that one was unable to solve a mathematics problem. Male students rarely tutored others (mean score = 2.93), but female students were even less likely to do so (mean score = 3.33). On average, female students expressed that they were sometimes unable to solve a problem (mean score = 1.98), while male students were less likely to claim they encountered such difficulties (mean score = 2.54). Although not significant, borderline differences suggested that the females might have been more likely to have given up on a problem.

Almost no students attended any special mathematics lectures or participated in the mathematics club (all mean scores above 3.60), surprising perhaps given that these are some of the most mathematically talented of the entering students. Most students, on the other hand, were at least sometimes involved in study groups, conquering difficult material, and feeling that hard work paid off (all mean scores near 2.0 or below).

Despite the minimal gender differences so far, retention in the first year Honors mathematics courses suggests other factors contributing to a differential experience (see Table 4). Students gave many reasons for leaving one of the Honors mathematics sequences (multiple, non-ranked responses were allowed). Over half of the students who left Honors mathematics, male or female, expressed their perception that the material was unnecessary for their program (55% of the males, 71% of the females, not a statistically significant difference). Inadequate preparation and poor instruction were selected by males and females at comparable rates (between a quarter and a third of the respondents). However, males more often selected two reasons of an external nature than females (heavy course load and outside factors), and females more often selected one reason of an internal nature than males (uninterested in material).

Subsequent areas of academic study

The marked difference in the proportion of men versus women who continued in mathematics after dropping the Honors sequence is greater than might have been predicted on the basis of their mathematics experiences. A better understanding of the possible underlying causal influences comes when we consider the students' areas of academic interest. Table 5 summarizes the areas of concentration, both the intended majors (as represented by their first year plans) and their subsequently declared concentrations.

Fewer than half of the entering Honors mathematics students were planning to concentrate in a natural science field (49% of the males and 40% of the females). When the mathematics and physical sciences (chemistry, physics, statistics, engineering, etc.) are distinguished from the medical and life sciences (biology, nursing, etc.), strong gender differences are apparent. Overall, 36% of the males intended to pursue a concentration in mathematics or the physical sciences, and 13% aspired toward a degree in medicine or the life sciences. This is reversed for the females, only 13% of whom were intending to concentrate in mathematics or the physical sciences, with 28% considering a degree in medicine or the life sciences. The largest group for either gender was composed of those students with no intended major; 40% of the males and 35% of the females had no explicit intentions as first year students.

Nearly identical proportions of males and females actually declared a natural science concentration (48%), about as many males as had originally intended and slightly more females than had intended. Upon closer examination of the relationship between intended and declared concentration, and not apparent from Table 5, is the amount of change between those time points. The suggested stability of the percentage of males majoring in the sciences masks the fact that 36% of the male students who originally intended to major in the natural sciences did not do so, while 35% of the formerly undecided males declared a natural science concentration. Similar changes occurred for the females where 25% of the females who originally intended to major in the natural sciences did not do so, and 29% of the formerly undecided females ultimately declared a natural science concentration.

As before with intended majors, making the distinction between the physical and life sciences is crucial for detecting the underlying gender differences between actual choice of major: the males selected the physical sciences over the life sciences (35% versus 12%) and the females selected the life sciences over the physical sciences (33% versus 15%). Because the life sciences (as well as the social sciences and humanities) usually require less mathematics training than the physical sciences, this disparity may partially explain some of the gender difference in retention. If fewer than two years of mathematics is required for a concentration program (which is the case except for the mathematics and physical science majors), a student might discontinue Honors mathematics without needing to continue to take non-Honors mathematics courses.

Achievement and factors necessary for success

Tables 6 and 7 reflect the academic performance of the Honors mathematics students during their later years at the University, including the factors that they felt were important for success in their respective concentrations. It is important to remember that these students now represent very heterogeneous groups with respect to their area of concentration.

Men and women Honors mathematics students entered with comparable high school grades (approximately a B+ average), and maintained similar grades within their area of concentration. The women students had slightly higher overall grade point averages than the men. Both groups equally felt that their college grades reflected "fairly well" what they had learned.

The male and female respondents tended to agree more than disagree about the factors important to a successful performance in their concentration programs. This is, perhaps, all the more surprising, given the diversity of concentration programs and the previously exhibited gender differences in program choice. Both groups cited intrinsic interest, effort, natural ability, and quality of instruction as among the most helpful factors; understudying, the breakup of a relationship, and academic anxiety were among the most harmful factors.

Women appeared to be more sensitive to environmental issues, rating a cooperative atmosphere more helpful and a competitive atmosphere more harmful than did the males. Women also tended to view differential treatment by gender as more harmful, with the men, on average, finding this issue irrelevant.

Gender and ethnic influences

When asked if gender in any way affects treatment of students in their department of concentration, over twice as many women students responded with "yes"--33% in comparison to only 16% of the men (see Table 8). When asked if gender has affected the student personally, 26% of the women responded "yes," but only 8% of the men. Of those students, male or female, who claimed the existence of gender bias, the overwhelming majority felt that the bias was against women.

Ethnic bias was claimed by fewer females than gender bias. Only 18% of the females felt ethnicity to be an influential factor, almost half the number of females who felt that gender had an influence. A comparable number of males cited ethnic bias or gender bias: 16% in both cases. The majority of all students who claimed ethnic bias felt that the bias was against students of ethnic and racial minorities.

Post-college plans

Table 9 indicates the immediate post-college plans of the Honors mathematics students. Comparable proportions of men and women were planning to enter graduate school in non-mathematics/non-physics areas (approximately 60%). Three times more men (18%) than women (5%) planned to attend graduate school in mathematics or physics, whereas women indicated a greater likelihood that they would teach or work in a non-research/industry setting.

Although failing to reach statistical significance, male/female differences in students' post-college plans were in keeping with previous trends. Similar to their current undergraduate concentrations, women more often had plans to pursue medicine and the life sciences (42% of those females who are planning on attending graduate school plan to do so in this area) while more often men were headed in the direction of mathematics and the physical sciences (31% of those males who are planning on graduate school plan to do so in this area).

Borderline significant differences are evident within intended career choices, with the same patterns as before: more women going into medicine, more men into mathematics and physics.

Discussion and conclusion

We began this investigation into the first year Honors mathematics students with the assumption that the students' unique mathematical strengths made them an excellent pool of prospective mathematics/science concentrators. As such, their experiences, especially during the early formative semesters, might help to explain some of the documented gender differences that are so apparent by the end of the undergraduate and into the graduate years. Previous academic and social forces already restricted the number of female students in our pool; fewer than 30% of the Honors mathematics students were women despite the fact that over 40% of the incoming General Honors students were female.

Almost no gender-based differences in students' self-described classroom behaviors emerged within the Honors mathematics students, the exceptions being the greater likelihood of women to admit to feeling unable to solve a mathematics problem and their lesser likelihood to be tutoring others in mathematics (see Table 3). However, the female students were much more likely to discontinue Honors mathematics and enroll in no subsequent mathematics courses, while the male students were equally likely to discontinue Honors mathematics (a very high attrition rate for both men and women of 85%), but were more likely to continue on with non-Honors courses. One factor that may account for some of the difference is the fact that women students were more likely to pursue academic programs with fewer mathematics course requirements.

Just under half of our pool of prospective mathematics/science concentrators ultimately selected a mathematics/science concentration. This proportion is similar to the proportion who initially intended to select such a major, but this fact masks the shifting decisions of individuals. We saw a quarter to a third of the students initially interested in the natural sciences leaving this domain, with a comparable number of formerly undecided students electing a science or mathematics concentration. Hence, these early experiences in mathematics and science courses may screen out some individuals, but attract others. These forces seem to work equally for males and females.

There was a sharp distinction between the specific areas of natural science selected by men and women. The female science and mathematics students were twice as likely to be pursuing degrees in biology, pre-medicine, and the life sciences as degrees in the mathematics and physical sciences. Conversely, the male science and mathematics students were twice as likely to be pursuing degrees in the physical sciences as the life sciences. The cause of this is not clear, but appears to pre-date the students' entrance into the University. These plans are not rigidly determined, however, as witnessed by the shifts from intended to actual concentrations. Hence, university-level efforts have the potential to affect concentration decisions.

In regard to classroom bias, female students were more sensitive to the presence of gender and ethnic biases, or at least cited their existence at a higher rate. They were also more sensitive to environmental influences, rating a cooperative setting more beneficial and a competitive setting more detrimental than did their male peers.

In summarizing our findings two issues seem paramount: (1) the purpose and intentions of the first year Honors mathematics courses, and (2) the incisively drawn gender divisions in the areas of natural science study.

Even with such a high attrition rate (85%), it is not clear whether or not the Honors mathematics courses are failing in some important manner. Without a more explicit formulation of the goals of these courses, it is impossible to determine a suitable reaction to the low completion rate. Students who choose concentrations outside of mathematics and the physical sciences will not in general need to complete a four semester calculus sequence (this is in keeping with the large percentage of students who discontinued Honors mathematics because the material was considered unnecessary). Whether or not more active recruitment is desirable--either in an attempt to attract more students into mathematics and the physical sciences, or simply to encourage completion of an Honors sequence regardless of concentration--is a consideration to be discussed in conjunction with the program.

During the previous two years (after the time of our sample), a new two-semester Honors mathematics sequence was created as an alternative to the first two terms of the intermediate Honors mathematics courses. These courses offer an alternative advanced curriculum (calculus and combinatorics) within an alternative learning environment (emphasis on conjectures, discoveries, and computer simulation). After completion of these two courses, students are eligible to enter the original Honors mathematics sequence at the third semester level. Early indications suggest a much higher retention rate in these new courses than in the other Honors mathematics courses, and determining the factors that may account for their holding power warrants further inquiry.

The origin of the gender differences in choice of natural science sub-areas is clearly a concern at all educational levels, as these differences are already strong before undergraduate education begins. However, there is little evidence to suggest that the University experience works to diminish this division. Whether or not the University experience reinforces the division is also unclear.

Table 1

DESCRIPTION OF SAMPLE

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Number of respondents	108	40	
Ethnicity:			n.s.[a]
% White	80	78	
% Black	2	5	
% Hispanic	0	3	
% Asian	17	15	
% Other	1	3	
Current Class level:			7.75 (p=.051)
% Sophomore	1	0	
% Junior	45	69	
% Senior	48	31	
% Graduate or out of school	6	0	
Honors mathematics course during first year:			
% in Mathematics 185	79	80	
% in Mathematics 195	21	20	

[a]not significant (p>.10)

Table 2

INITIAL ENCOURAGEMENT INTO HONORS MATHEMATICS

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Encouraged to take Honors Mathematics?:			5.47 (p=.065)
% Encouraged	73	58	
% Discouraged	9	5	
% Neither	18	37	

Table 3

STUDENT BEHAVIOR IN MATHEMATICS CLASSROOMS[a]

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	T-test
Conquered something difficult	1.69	1.80	n.s.[b]
Felt hard work paid off	1.84	2.05	n.s.
Study with others	2.07	2.00	n.s.
Ask questions	2.07	2.33	n.s.
Gave up on a problem	2.26	1.95	1.94
Talk with professor	2.29	2.48	n.s.
Socialize with math students	2.38	2.28	n.s.
Made mistake and later recouped	2.40	2.54	n.s.
Felt unable to solve a math problem	2.52	1.98	3.50***
Felt course was over your head	2.78	2.60	n.s.
Tutored others in mathematics	2.93	3.33	-2.32*
Attend special mathematics lectures	3.61	3.75	n.s.
Participated in mathematics club	3.77	3.70	n.s.

[a] all variables coded: 1=often, 2=sometimes, 3=rarely, 4=never

[b] not significant (p>.10)

*p<.05, **p<.01, ***p<.001

Table 4

RETENTION IN HONORS MATHEMATICS

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Student Status:			9.57** (p=.008)
% Dropped Honors mathematics, and took no further mathematics	31	58	
% Dropped Honors mathematics, but continued in mathematics	54	28	
% Completed Honors sequence	15	15	
Reasons for Dropping Honors Mathematics[a]:			
% Scheduling conflict	5	3	n.s.[b]
% Heavy course load	26	9	4.12* (p=.042)
% Poor instruction	26	21	n.s
% Inadequate preparation	27	35	n.s.
% Not interested	32	56	5.77* (p=.016)
% Outside factors	35	15	4.31* (p=.038)
% Material unnecessary	55	71	n.s.

[a] multiple responses allowed

[b] not significant ($p > .10$)

*$p < .05$, **$p < .01$, ***$p < .001$

Table 5

INTENDED MAJORS AND ACTUAL MAJORS

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Intended majors, by area:			
% Mathematics/physical sciences	36	13	16.78** (p=.005)
% Medicine/life sciences	13	28	
% Social Science	4	10	
% Humanities	3	0	
% Other	5	15	
% Unknown	40	35	
Current majors, by area:			15.74** (p=.008)
% Mathematics/physical sciences	35	15	
% Medicine/life sciences	12	33	
% Social Science	26	13	
% Humanities	9	13	
% Other	17	28	
% Unknown	1	0	

*p<.05, **p<.01, ***p<.001

Table 6

GRADES[a]

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	T-test
Self-Reported from Survey:			
High school GPA	3.58	3.36	0.99
Overall college GPA	3.38	3.53	-2.12*
GPA, in major	3.51	3.55	0.61
Grades are reflective of what I've learned[a]	2.12	2.16	-0.24
From Registrar's Office:			
SAT verbal[b]	634	665	-1.79
SAT mathematics[b]	728	708	1.93
ACT mathematics[b]	32.2	30.6	1.26
Honors mathematics[c] course grade	3.22	3.38	-1.14

[a] variable coded: 1=very well, 2=fairly well, 3=not very well, 4=not at all well
[b] College Board scores available only for the Fall term 1988 students
[c] includes student grades for the entire population, $n_{males}=127$, $n_{females}=46$

*p<.05, **p<.01, ***p<.001

Table 7
FACTORS IMPORTANT TO PERFORMANCE IN CONCENTRATION PROGRAM[a]
(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	T-test
Intrinsic interest[b]	1.18	1.18	n.s.[c]
Effort	1.43	1.23	n.s
Natural ability	1.50	1.51	n.s.
Quality of instruction	1.58	1.45	n.s.
Studying with others	1.92	1.88	n.s.
Cooperative atmosphere	1.93	1.63	2.17*
Same-sex faculty member	1.93	2.05	n.s.
Same-sex friends in field	2.15	1.93	n.s.
Grading practices	2.67	2.55	n.s.
Outside employment	2.68	2.75	n.s.
Competitive atmosphere	2.88	3.33	-2.26*
Treated differently by gender	2.97	3.28	-4.36***
Overstudying	3.00	3.08	n.s.
Academic anxiety	3.49	3.44	n.s.
Breakup of a relationship	3.49	3.48	n.s.
Understudying	4.12	4.28	n.s.

[a] concentration program not necessarily mathematics or science
[b] all variables coded:
1=helps a lot, 2=helps some, 3=irrelevant, 4=hurts some, 5=hurts a lot
[c] not significant (p>.10)

*p<.05, **p<.01, ***p<.001

Table 8
GENDER AND ETHNIC INFLUENCES IN CONCENTRATION PROGRAM[a]
(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Gender affects treatment in your department? (% yes)	16	33	5.07* (p=.024)
If yes, how?:			n.s.[b]
% Bias against women	67	93	
% Bias for women	0	0	
% Mixed	5	0	
% Unclear	0	7	
Gender affects you in your department? (% yes)	8	26	7.63** (p=.006)
If yes, how?:			n.s.
% Bias against women	67	83	
% Bias for women	22	8	
% Unclear	11	8	
Ethnicity affects you in your department? (% yes)	16	18	n.s.
If yes, how?:			n.s.
% Bias against ethnic minority	29	29	
% Bias for ethnic minority	0	14	
% Bias against racial minority	35	14	
% Bias for racial minority	18	14	
% Unclear/other	18	29	

[a]concentration program not necessarily mathematics or science
[b]not significant (p>.10)

*p<.05, **p<.01, ***p<.001

Table 9

POST-COLLEGE PLANS:
FIRST YEAR AFTER GRADUATION

(FIRST YEAR HONORS MATHEMATICS STUDENTS)

	Male	Female	Chi-square
Are you planning: (p=.037)			13.39*
% Work (industry-research)	3	0	
% Work (teach high school)	0	8	
% Work (other)	18	23	
% Graduate school (mathematics)	11	5	
% Graduate school (physics)	7	0	
% Graduate school (other)	56	60	
% Don't know	6	5	
If graduate school, what area?: (p=.073)			10.07
% Mathematics/physical sciences	31	13	
% Medicine/life sciences	16	42	
% Social sciences	11	4	
% Humanities	9	13	
% Other	21	13	
% Unknown	13	17	
Intended career: (p=.053)			12.44
% Mathematics/Physics	8	0	
% Business/Law	20	15	
% Medicine/Health	19	33	
% Government/Industry	6	3	
% Academia/Research	25	23	
% Arts/Music/Literature	5	5	
% Other	9	23	

*p<.05, **p<.01, ***p<.001

C. Mathematics/Physics Majors Study

Introduction

The Honors Mathematics Study found little difference in the ability of the men and women they studied, but there was a difference in the perceptions of some of their experiences. These differences may have led to the larger attrition of women from Honors mathematics courses. Are there gender differences among the mathematics and physics majors? Not many. What few there are, however, are consistent with the Honors Mathematics Study--little difference in ability, but some differences in perception.

The differences in perception seem to revolve around issues of encouragement by faculty, which is especially notable in light of the literature review findings about women's lower levels of confidence. Women were less likely to find encouragement in their respective departments than men were. They found their professors less likely to take a special interest in them as students, and their advisors less likely to encourage them to take challenging courses. They also reported a slightly lower grade point average in their mathematics courses and a slightly lower sense of confidence about their mathematical skills overall than did the men.

Description of Sample

We sent out survey questionnaires to all graduating seniors of the Class of 1990 who had declared a mathematics or physics major. We followed this up with telephone interviews of those who had not replied by the end of the academic year. The final response rate was 86.2% (N=75). As the total sample is quite small, much of what follows is necessarily descriptive.

Table 1 presents an outline of the final sample. There were twice as many men as women who graduated in 1990 with mathematics and physics majors--58 men and 29 women, 67% and 33%, respectively. Our sample is clearly representative of the total class which included 65% males and 35% females (Ns of 49 and 26, respectively).

The ethnic breakdown indicates that both the males and females were predominantly white with only a few African-American, Hispanic and Asian students. While there is no significant difference for major (mathematics versus physics) by gender, there were somewhat more female than male mathematics majors and very few female physics majors.

There were also gender differences in choice of subspecialty within mathematics. The breakdown for mathematics subspecialty which we obtained from their class records reveals that more females than males had chosen teaching (25% vs. 7%) while most of the males were in pure and applied mathematics (62% vs. 46%). Almost equal numbers were in actuarial mathematics (about 30%).

The Mathematics/Physics Major Experience

Students go through a variety of academic experiences during their four years of college, some of them directly relevant to choosing a major and persisting in their chosen field. We asked the graduating seniors to identify the most influential courses they had taken at the University of Michigan--both positively and negatively--and what effect they had had on their enthusiasm for majoring in their field. The question was open-ended and their responses were many and varied.

Table 2 lists the most often cited characteristics of those classes. The most striking finding is that the women cited the instruction of the class as the most influential factor in contributing to their knowledge and understanding, regardless of whether they thought that class had made the greatest or the least contribution. If they liked a course, it was because it had an excellent instructor and was well-taught (67%). If they disliked a course, it was because it was poorly taught or the professor was difficult to understand (75%). They also gave other responses but not as frequently.

Men's responses were not as focused, and the quality of instruction was less influential for men. They would more often reply that the material was interesting (43%) or the class added to their understanding (33%) or it was challenging (33%) as the reasons for choosing a course as most positively influential. Good teaching was relatively low on their list (29%). Poor teaching was, however, the reason given most often for nominating a mathematics or physics course for having made the least contribution to their studies (56%). But it was closely followed by the response that the material was dry and uninteresting (44%).

Why women should be more likely to focus on the teaching of classes is at this point unclear. But it is clear that good teaching plays an important role in drawing women into mathematics classes. And it is noteworthy that poor teaching is the largest indicator for both men and women for turning students off and sometimes for their dropping out of mathematics and physics classes.

The Mathematics and Physics Honors Programs offer an incentive for good students to take rigorous and challenging courses. Although there was a decided difference in the experiences of men and women as to whether they were informed of the honors classes and whether they were encouraged to take them, roughly equal numbers of men and women mathematics and physics majors took honors courses during their years at the University, 14% vs. 12% (see Table 3).

More men than women remember being informed of the honors classes (53% vs. 38%). This may be because there were more men in the overall Honors Program, all of whom were informed of the mathematics honors classes.

Among those who were informed, 52% of the men said someone encouraged them to take honors, but only 10% of the women said so. No woman felt she was discouraged, but fully 90% of the women felt they were neither encouraged nor discouraged to take honors classes in sharp contrast to 33% of the men. This is a very similar result to that found among accelerated mathematics students who chose to discontinue honors classes, as noted in the previous study.

There were no significant gender differences in other areas of the students' experiences. About half the students entered the University of Michigan with the intention of majoring in something other than mathematics, physics and engineering, but revised their plans and finished as mathematics, physics or engineering majors (see Table 4).

Students generally decided on their major in their sophomore and junior years (66%), although about a quarter of them considered changing their majors at some point. For mathematics and physics majors, the single most often considered alternative was engineering and computer science, but fully half the students considered taking a non-science major.

As with the Honors Mathematics Study, majors were asked to rate the frequency of several activities in their mathematics or physics classes (on a scale from 1=often to 4=never). Table 5, which summarizes their responses with a mean score on each item, indicates that there was only one significant gender difference among the thirteen activities. While the males noted that they sometimes attended special lectures in their department (mean score = 2.35), females were "rarely" to "never" likely to do so (3.42). Unlike their female counterparts in honors who tended to discontinue honors mathematics, these women were not any more likely than the men to have "felt so stuck" that they gave up on a problem (2.33 vs. 2.27).

Like the honors students, the majors--male and female--were most likely to say that they felt good that they were able to conquer something that at first seemed too difficult for them. They also "often" to "sometimes" felt that their hard work paid off. They studied with other students and asked questions in class. They were "rarely" likely to feel throughout a course that it was far above their level. And few of either gender participated in activities of the Mathematics/Physics club.

Perceptions of Faculty/Program

As reported earlier, more women than men found a lack of encouragement in terms of the honors mathematics program. Does this extend to other experiences with faculty members?

Table 6 confirms that the perception of lack of encouragement was more pervasive among female students than male students. Whereas almost three-quarters of the men told us that a professor had taken a special interest in them as a student, less than half of the women did so. Among those who felt they were encouraged--and almost half of the women did--most said a professor had counseled them about course work. Few students of either gender did any research or special projects with a professor or graduate student while they were at Michigan.

Not only is there a perception of lack of encouragement among women in the Mathematics and Physics Departments, but more active discouragement was reported by the women as well. Table 7 presents responses to a question about whether any professors had had a particularly discouraging effect on the student's interest in mathematics or physics. Over half (54%) of the women said yes, compared to 38% of the men. The form this discouragement took varied. Most often it was just poor teaching, but women also noted a particular type of discouragement--discouraging comments--made by faculty.

We find additional evidence of discouragement, and a greater focus on teaching as evidence of that discouragement, in the students' responses to questions about concentration advisors. First, over half of the students replied that they had never had a regular concentration advisor, 63% of the males and 46% of the females (see Table 8). At the same time, they felt that the advisors they did have were very good or good in most respects, but especially in knowing the facts about courses and encouraging them to take challenging courses. Women graded their advisors considerably lower than did men on encouraging them to take challenging courses (2.23 versus 2.92 where 2=very good and 3=good). The factors that received the lowest grades were providing career information (3.02 versus 3.12) and directing students to good courses and teachers (3.02 versus 3.19). For the latter factor the difference between males and females is significant.

Feelings about lack of challenge were reflected in students' comments about changes in the program. When we asked them if the degree requirements were reasonable, over three-quarters said yes. But they also offered some constructive criticism about a few things that could be different. Men again gave more varied responses than women and mostly mentioned a specific class that might be added. Women, however, focused heavily on challenge. Half of those who responded to this question felt that the requirements were too lenient. (See Table 9.)

Achievement and Factors Necessary for Success

As noted earlier, the Honors Mathematics Study found little difference in ability between the male and female students but greater differences in perceptions. Such is the case among the mathematics/physics majors as well.

Women and men performed equally well, according to their self-reported grade point averages for high school and college overall (see Table 10). However, there was a near-significant tendency for the women to have a slightly lower mathematics/physics grade point average than men (3.27 vs. 3.02). Both men and women felt their grades were fairly well reflective of what they had learned at the University although women were less certain of that than the men (2.10 vs. 2.40).

When asked to rate their level of confidence in a series of mathematics skills, men and women for the most part responded equally (see Table 11). But taking an average across all mathematics skills reveals a near-significant difference. The overall mean of the seven items was 1.89 for men where 1=completely confident and 2=somewhat confident. For women, it was 2.05.

Most students derived their confidence from the following skills: algebraic manipulation, mathematics intuition, formal mathematics, geometric or spatial perspectives and applying mathematics to other sciences. Both men and women felt less confident about their ability to conjecture new results and do formal rigorous proofs. The largest difference between males and females is found in this latter skill, though this was not significant. Women were "not very confident" that they could do formal rigorous proofs, whereas men felt "somewhat" confident (3.04 and 2.69, respectively).

Similarly, males and females tended to agree more often than not on what factors were important to their academic performance in their concentration programs. (see Table 12). Foremost among these were an intrinsic interest in the subject, effort, a natural ability in the subject matter, and the quality of instruction. All agreed that the three factors most harmful to their performance were the breakup of an important relationship, academic anxiety and understudying. This same configuration of factors was evident among the Honors mathematics students.

On the other hand, male and female students responded differently with regard to three factors affecting their performance: the influence of their gender, grading practices and studying with other students. Men were more likely to say that having a faculty member of their gender take an interest in them had helped them in their program (see Table 12). They also noted that being treated differently because of their gender had had the same effect (2.85 vs. 3.15). Women, on the other hand, felt they had profited more from the grading practices in mathematics/physics courses (2.29 vs. 2.93) and in studying with other students (1.65 vs. 2.09). Indeed, studying with other students is the most highly rated factor among women.

Gender Influences in Concentration Program

The influence of gender was again evident when the students were asked directly if they noted any differences in the departments in the treatment of students by gender. About a quarter of both males and females said they had noticed that gender affected the treatment of students in their department (Table 13). The women, more than the men, believed that this took the form of bias against women, 86% vs. 39%. The men were more unclear as to whether women were or were not treated unfavorably. While a few (8%) indicated there was a bias for women, others (8%) noted a bias against all students, but most (46%) gave an ambiguous response.

Post-college Plans

Table 14 outlines the immediate post-college plans of the mathematics/physics majors. Observing individually where the students planned to work or what area in graduate education they were pursuing reveals no gender difference. It is when a composite is made of work versus graduate school plans that a trend becomes evident. The female graduates were more likely to be taking a paid position (62% vs. 39%) and the males were going to graduate school (27% vs. 48%). This is probably an outcome of their subspecialities with women more likely to be teachers and actuaries. But it also highlights a finding in the literature that women, regardless of ability, are less likely to follow the traditional path from undergraduate to graduate school.

Discussion and Conclusion

The experiences and attitudes of all mathematics and physics majors at the University of Michigan reveal a strong emphasis on the importance of good teaching and the need for faculty encouragement for women students. This lack of encouragement was perceived by the women in several types of faculty interactions: less encouragement to take more challenging or better taught courses either in honors counseling or in concentration advisor counseling; no special interest taken by professors; active discouragement by poor teaching and discouraging remarks. Clearly, this lack of encouragement does not result from the fact that the women are poor students. Indeed, not only do they do nearly as well as the men, but they even suggest program changes because they deemed the requirements too lenient.

The results from our surveys, coupled with findings from other researchers, reveal that good teaching, faculty encouragement, and providing appropriate challenges are important factors in creating learning environments which foster the self-confidence and achievement of women.

Table 1

DESCRIPTION OF SAMPLE

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Number of Respondents	49	26	
Ethnicity			ns[a]
White	86%	89%	
Black	0	4	
Hispanic	2	0	
Asian	4	8	
Other	8	0	
Major			ns
Mathematics	58%	92%	
Physics	35	8	
Mathematics and Physics	4	0	
Other combined program	2	0	
Mathematics Subspecialty			
Teaching	7%	25%	ns
Actuarial	31	29	
Pure and Applied	62	46	
(N)	(29)	(24)	

[a]not significant (p=>.10)

Table 2

CHARACTERISTICS OF INFLUENTIAL MATHEMATICS/PHYSICS COURSES

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females
Positive Influences[a]		
Excellent instructor; well-taught	29%[b]	67%
Material was interesting; fun	43	33
Added to my understanding	33	47
Rigorcus; challenging	33	13
Reaffirmed my interest in the area for major/as career	24	33
General comments; great; good	17	0
Prerequisite; required for major	12	7
No effect	2	0
Other	5	0
(combined N)	(42)	(15)
Negative Influences[a]		
Poorly taught; professor difficult to understand	56%	75%
Material was not interesting; dry	44	40
Useless course; terrible class	23	31
Material was too abstract	9	25
Made me consider changing my major	9	0
General comments; disliked it	5	0
Required course	14	0
No effect	2	0
Other	9	13
(combined N)	(43)	(16)

[a]Students were asked to list the courses they had taken at Michigan which had made either the greatest or the least contributions to their knowledge and understanding of their field. They were then asked to explain briefly why they chose that course and how it had affected their enthusiasm for majoring in their field.

[b]Open-ended question. Multiple response allowed. Does not add to 100%.

Table 3

HONORS MATHEMATICS AND PHYSICS PROGRAM

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Informed of Honors?			5.40 (p=.07)
% Yes	53%	38%	
(N)	(49)	(24)	
If Yes: Encouraged/Discouraged to take Honors?			10.11* (p=.02)
Encouraged	52%	10%	
Discouraged	15	0	
Neither	33	90	
(N)	(27)	(10)	
Percent taking Honors course			
% Yes	14%	12%	ns
(N)	(49)	(26)	

*p<.05, **p<.01, ***p<.001

Table 4
SELECTION OF MAJOR
(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Intended major at enrollment			ns
Engineering	10%	23%	
Mathematics	15	32	
Physics	23	5	
Other	53	41	
(N)	(40)	(22)	
Level of commitment to intended major[a]			T-test
% Yes	1.50	1.35	ns
(N)	(44)	(23)	
When decision made to major in mathematics/physics?			Chi-square
			ns
Before college	18%	13%	
Freshman	16	17	
Sophomore	33	46	
Junior	33	21	
Senior	0	0	
(N)	(43)	(24)	
Other majors considered at that time			
			ns
Engineering	11%	22%	
Computer Science	14	9	
Chemistry	11	4	
Physics	11	4	
Mechanical Engineering	5	9	
Other	49	52	
(N)	(37)	(23)	
Ever consider changing major?			ns
%Yes	22%	28%	
(N)	(49)	(25)	

[a]Variable ranges from 1=strong commitment to 5=weak commitment.

Table 5
FREQUENCY OF STUDENT BEHAVIORS
IN CONCENTRATION PROGRAM
(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	T-test
Felt good that you were able to conquer something that at first seemed too difficult for you	1.67[a]	1.46	ns
Felt that your hard work paid off	1.75	1.69	ns
Studied with other students	2.00	1.92	ns
Asked questions in class	2.06	2.35	ns
Tutored others in mathematics/physics	2.08	2.50	ns
Talked over problems with a professor	2.30	2.15	ns
Socialized with other mathematics/physics majors	2.31	2.31	ns
Attended special lectures in your department	2.35	3.42	-3.05**
Felt so stuck that you gave up on a problem	2.33	2.27	ns
Felt you would never be able to solve an assigned problem	2.42	2.15	ns
Made a big mistake in solving a problem (or on a test) and later recouped	2.49	2.38	ns
Felt throughout a course that it was way above your level	2.81	2.50	ns
Participated in activities of the Mathematics/Physics club	3.25	3.50	ns

[a]All variables were coded 1=often, 2=sometimes, 3=rarely, 4=never.

*p<.05, **p<.01, ***p<.001

Table 6

ENCOURAGEMENT BY FACULTY

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Professor take special interest in you as a student?			6.08* (p=.05)
% Yes	72%	46%	
(N)	(47)	(26)	
If yes: In what ways have they expressed that interest?			ns
Counseling: grad school, work	19%	20%	
Counseling: course work	31	40	
Counseling: other	8	0	
Nonspecific: helpful, encouraging	19	20	
Other	23	20	
	(26)	(10)	
Have you done research (or special project) with professor (or teaching assistant/graduate student) while at Michigan?			
% Yes	29%	19%	ns
(N)	(48)	(26)	

*p<.05, **p<.01, ***p<.001

Table 7

DISCOURAGEMENT BY FACULTY

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Have any professors had a particularly discouraging effect on your interest in math/physics?			6.08* (p=.08)
% Yes	38%	54%	
(N)	(45)	(24)	
If yes: What did they do to discourage you?			ns
Poor teacher	44%	23%	
Lack of enthusiasm	6	15	
Lack of patience/sympathy	19	15	
Made discouraging remarks	6	23	
Other	25	23	
(N)	(16)	(13)	

*p<.05, **p<.01, ***p<.001

Table 8

CONCENTRATION ADVISOR

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Ever had regular concentration advisor?			ns
% Yes	63%	46%	
(N)	(49)	(26)	
How good was the advisor[a] at			T-test
Knowing the facts about courses	2.08[b]	2.46	ns
Encouraging you to take challenging courses	2.23	2.92	ns
Making concrete suggestions	2.60	2.80	ns
Getting to know you and your interests	2.84	3.04	ns
Helping you clarify your academic plans	2.84	3.08	ns
Providing career information	3.02	3.12	ns
Directing you to good courses and teachers	3.02	3.19	-2.34*
Overall mean of seven items	2.67	2.92	ns

[a]The following questions were asked about either a regular concentration or about advisors in general.

[b]All variables were coded 1=excellent, 2=very good, 3=good, 4=fair, 5=poor.

*p<.05, **p<.01,***p<.001

Table 9

CHANGES IN PROGRAM

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Degree requirements reasonable?			
% Yes	75%	85%	ns
(N)	(48)	(26)	
If no, what changes?			ns
Add specific class	38%	25%	
More integration of courses	13	0	
Eliminate specific class	13	0	
Requirements too lenient	6	50	
Other	31	25	
(N)	(33)	(22)	

Table 10

GRADES[a]

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	T-test
High school G.P.A..	3.77	3.77	ns
(N)	(49)	(26)	
Overall college G.P.A.	3.22	3.12	ns
(N)	(48)	(25)	
G.P.A. in major	3.27	3.02	1.95 (p=.055)
(N)	(45)	(24)	
Grades are reflective of what I've learned[b]	2.10	2.40	ns
(N)	(48)	(25)	

[a]All grades are self-reported

[b]Variable was coded 1=very well, 2=fairly well, 3=not very well, 4=not at all well

Table 11

CONFIDENCE IN MATHEMATICS SKILLS

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	T-test
1. Algebraic manipulation	1.18[a]	1.19	ns
2. Mathematics intuition	1.71	1.77	ns
3. Formal mathematics	1.74	1.79	ns
4. Geometric or spatial perspectives	1.78	2.00	ns
5. Applying mathematics to other sciences	1.83	2.08	ns
6. Conjecturing new results	2.30	2.50	ns
7. Formal rigorous proofs	2.69	3.04	ns
Overall mean of seven items	1.89 (48)	2.05 (26)	-1.76 (p=.08)

[a]All variables were coded 1=completely confident, 2=somewhat confident, 3=not very confident, 4=not at all confident.

Table 12
FACTORS IMPORTANT TO PERFORMANCE IN CONCENTRATION PROGRAMS
(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	T-test
Intrinsic interest in the subject	1.56[a]	1.88	ns
Effort	1.58	1.73	ns
Natural ability in the subject matter	1.69	1.69	ns
Quality of instruction	1.90	2.12	ns
Studying with other students	2.09	1.65	2.11*
Having a faculty member of your gender take an interest in you	2.25	2.87	-3.86***
Cooperative atmosphere in math/physics classes	2.30	2.12	ns
Friendships with other math/physics majors of your gender	2.32	1.96	ns
Outside employment	2.72	3.12	ns
Overstudying	2.83	2.73	ns
Being treated differently because of your gender	2.85	3.15	-3.10**
Competitive atmosphere in mathematics/physics classes	2.92	3.27	ns
Grading practices in mathematics/ physics courses	2.93	2.29	2.72**
Breakup of an important relationship	3.30	3.42	ns
Academic anxiety	3.42	3.46	ns
Understudying	3.94	3.85	ns

[a]All variables were coded 1=helped a lot, 2=helped some, 3=irrelevant, 4=hurt some, 5=hurt a lot.

*p<.05, **p<.01, ***p<.001

Table 13

GENDER INFLUENCES IN CONCENTRATION PROGRAM

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Gender affects treatment in your department			ns
% Yes	27%	23%	
(N)	(48)	(26)	
If yes, how?			
Bias against women	39%	86%	ns
Bias for women	8	0	
Bias against all students	8	14	
Unclear	46	0	
(N)	(36)	(19)	
Gender affects you in your department			
% Yes	10%	27%	ns
(N)	(49)	(26)	
If yes, how?			ns
Bias against women	100%	63%	
Bias for women	0	13	
Mixed	0	13	
Unclear	0	13	
(N)	(3)	(6)	

Table 14

POST-COLLEGE PLANS
FIRST YEAR AFTER GRADUATION

(MATHEMATICS/PHYSICS MAJORS)

	Males	Females	Chi-square
Are you planning:			ns
Work (industry/research)	9%	12%	
Work (teach high school)	5	12	
Work (other)	25	39	
Graduate school (mathematics)	16	12	
Graduate school (physics)	16	4	
Graduate school (other)	16	12	
Don't know	9	8	
Other	5	4	
(N)	(44)	(26)	
Composite			
Work (all three)	39%	62%	ns
Graduate school (all three)	48	27	
Don't know; other	14	12	
(N)	(44)	(26)	

D. Graduate Students in Mathematics and Physics

Introduction

Our purpose in convening focus groups of graduate students in mathematics and physics, was to investigate the experiences of women in graduate school, as well as to ask them to reflect upon their undergraduate experiences. We were interested in understanding the degree to which these past experiences influenced these women's lives, their choices and decision-making. We wanted to discern the common and idiosyncratic circumstances, feelings, and perceptions among women graduate students in mathematics and physics. What fostered their success? What barriers had they encountered? How had they made decisions to pursue graduate study?

Two focus groups, composed of women in the Mathematics and Physics graduate programs at the University of Michigan, were held in November, 1990. We obtained a list of 63 names of women graduate students in the two departments. Letters were sent to invite each woman to participate in the groups. Twenty-three women volunteered to participate. They were divided into two focus groups: one composed primarily of first year women in mathematics and physics and the other one composed of students in their third year or beyond. The groups reflected a rich depth of past and present experiences, and the focus group structure provided a comfortable semi-structured framework in which the women could discuss their experiences.

The first focus group (Focus Group One) included two women in master's programs in mathematics, six in mathematics Ph.D. programs and four in physics Ph.D. programs. Their undergraduate institutions represented the following: four women attended elite private universities; two attended research universities; two attended medium-sized private universities; two attended elite liberal arts colleges; one attended a public state university; and one attended college in a foreign country.

The second focus group (Focus Group Two) included nine mathematics Ph.D. students and two physics Ph.D students. Their undergraduate institutions were represented as follows: two attended elite private universities; two attended research universities; one attended an elite liberal arts college; one attended a medium-size public university; and three attended colleges in other countries.

In general, the women expressed their ideas and feelings clearly and in vivid detail. Since most of the women felt secure in the group's mission and in the guarantee of confidentiality, they were able to share their feelings about some very sensitive issues. These included their academic successes, humiliations and frustrations; gender biased remarks, attitudes and behaviors; and private as well as professional concerns and apprehensions about being a woman in the sciences.

The sessions began when each woman was asked, by one of the two moderators, to introduce herself and to describe her undergraduate experience. From that starting point, each group took a different direction. Focus Group One quickly began revealing encouraging and discouraging educational experiences in their lives as undergraduates. These women were able to describe freely such situations with little embarrassment or coaxing. Their details were rich and illustrative of both painful and exuberant experiences. Many women elaborated upon descriptions of certain encounters. Throughout the discussion it became clear that the experiences could be divided into two major categories: those which encouraged the woman to continue her scientific education and those which discouraged her from pursuit of her goal. Some women had gone to a professor for advice and walked away feeling powerless or ignorant or even betrayed. Other women encountered influential individuals who helped to change their lives for the better. Focus Group One was filled with these kinds of observations. That group was not afraid to stress the negative experiences or applaud the positive forces in their growth.

Some of the positive experiences expressed by Focus Group One included the support they received from their parents and encouragement from influential faculty members. One woman spoke about an undergraduate faculty member in this way,

> "She was so seminal in terms of creating my college experience in the math department. I am very lucky to have had her there. I notice her absence here."

Encouragement was also demonstrated in the personal interest that some faculty took in the welfare of their individual students and in the advice and assistance that faculty gave to their proteges. This included help given to students when critical decisions were being made about going to graduate school in the sciences.

In contrast, the lack of encouragement , also a major theme, was linked to the student's self-concept, goal articulation and her learning process. Some women made comments such as,

> "The whole time I was there...it ranged from discouragement to no encouragement. No one helped me with the application process for graduate school."

And another woman said,

> "There was not an ounce of encouragement or acknowledgement from the faculty."

While willing to share experiences, the members of Focus Group Two were somewhat more cautious about what they said and how much they said. They provided less detailed descriptions and often needed more guidance and prompting from the moderators. Given the distance from their undergraduate experiences, it is not surprising that their descriptions contained fewer vivid details. In addition, they appeared to be somewhat less willing to ventilate feelings about their experiences. They were more willing to concentrate on current feelings of having "survived" or having "made it through" the first part of their programs. Indeed, it is important to note that this group included only "survivors". Those who had not been successful in their graduate programs, or who had decided upon other career paths, were not included in the group.

Focus Group Two had a more neutral stance on the theme of encouragement. One woman said,

> "I really do not remember anyone encouraging me to go to graduate school. I just assumed I would go."

Another woman expressed a disappointment in the lack of involvement by faculty in her graduate program,

> "The disappointment was that faculty kept a distance at the beginning, like trying to figure out who was good. Not getting involved..."

Another student likened the early period in graduate school to,

> "boot camp...but once it's over it's much, much better in the third or fourth year. This is survival."

Other women made similar comments,

> "We can all say we're having a positive experience because we're still here."

and,

> "there are no first year students here tonight, they're still struggling..."

Once Focus Group Two found its sense of security and validation in other members, the discussion became more personal and descriptive, although the women never seemed as unintimidated as did the members of Focus Group One. Perhaps they felt more vulnerable to retaliation in case their identities were revealed or felt reluctant to share feelings or concerns in front of those who had become their colleagues. Perhaps because they had finished with the hardest parts of their initial graduate school training, they did not feel the need to share the intense experiences that the newer students were encountering for the first time.

Both focus groups were tape recorded and the recordings were later transcribed. These transcripts were then analyzed by several different researchers for discernible common themes and important, revealing individual themes. In the pages that follow we present text from the transcriptions as well as commentary where it is appropriate. The common themes are sub-divided for clarity as follows:

---Encouragement and the Lack of Encouragement
---Influential Persons
---Decision To Go To Graduate School
---Competition and Cooperation
---Negative Qualities of Graduate School
---Size of the Undergraduate School
---Positive Qualities
---Sexist Attitudes

The individual themes are those that were expressed by one or a small number of the participants, but that were deemed particularly revealing. They are discussed following the common themes.

Common Themes of Focus Group One: First Year Graduate Women

Encouragement and the Lack of Encouragement: During the discussion, participants described their undergraduate experiences with many similar comments about the important individuals and events that encouraged them to pursue their studies and careers in mathematics and physics. In addition, as they became more trusting and comfortable in the focus groups, some shared stories of negative experiences or discouraging events which somehow empowered them to continue in pursuit of their present educational goal. These patterns are classified as distinctly separate themes: the importance of encouragement and the importance of overcoming discouragement. The women identified the encouragement as coming from certain sources: parents, professors, other teachers and staff members.

> "No one discouraged me...I received quite a bit of encouragement from several professors."

> "[During college] in the Math department, my faculty members knew who I was, they took a real interest in what I was doing whereas in [another department] I was one of many and I think that all my professors knew was my name and that was it."

> "When I started college I wanted to be a physics major. I had a wonderful AP physics class in high school with an enthusiastic young teacher--I was the only girl and some things were weird but I really felt like I belonged. I did well and I liked it. But when I got to college, I hated physics lab and had a bad experience in my first class. My assigned freshman advisor, who happened to be in education, was leaving and she suggested that I ask my math professor to be my advisor. He was also chair of the math department and usually doesn't advise, but he said he'd be my

advisor, [and said] 'and then you'll be a math major, right?' He then asked me to be in his honors program seminar."

"I was encouraged to attend graduate school partly by my parents; both went to grad school in biochemistry."

"My family background--you continue, you go for your Ph.D., go as far as you can. Both my parents have advanced degrees and the research interest [was] started by my parents."

One woman turned to her father, who was a scientist, for advice in the midst of an agonizing decision.

"Both my parents are scientists. When I first went to college, I didn't want to be there and I eventually got about a 1.0 or below for three semesters in a row. So I quit school and took a year off. When I went back I switched my major from physics to math. The first week I was back at school I was really psyched about being back at school because I really wanted to be there and I really liked math and I had been looking at math while I was out of school. They wouldn't let me become a [math] major. A conversation with one advisor marked me for the next year and a half or two years. I still think about it and get really angry. He said I couldn't be a math major because I had gotten bad grades. He was very paternalistic about it, told me to take baby math classes, like baby group theory at a sophomore or junior level. I felt like he was trying to tell me in a gentle way that I was stupid. I talked to my dad about it and he said, 'Well if you're stupid, you might as well find out now' so I registered for three senior level math classes. I took a very heavy schedule. But the whole semester I felt like the department didn't want me and I had no contact with faculty and they thought I was just stupid or something. I worked extra hard to show them I wasn't stupid. That was kind of the low point but it didn't get much higher...No one helped me with the application process for graduate schools: When I asked a professor about graduate schools he discouraged me from going here and told me I should go some place where I would be happier. I was choosing between here and going to a particular west coast city and that was an issue for me. I would rather live in the west coast city than go here and i was basically asking him if the departments were comparable for what I was interested in and did it matter cause I didn't know the reputation of the two schools and he told me I'd be happier in the west if that's what I thought and it was more important to be happy. I had a male friend and he asked him a pretty much symmetrical question. He was choosing between here and another school that was not as good. And he [the professor] told the other guy 'You should go to Michigan, it's really important.' When I heard this I was mad and I changed my plans at the last minute because I was mad."

It seems reasonable to speculate whether a woman who received such discouragement would have had the drive and determination to succeed in science had she not had parents who were scientists. Another woman, who had the support of her parents also took teacher discouragement as a challenge to be overcome.

"I don't think I had any particular encouragement. My high school physics teacher was a real male chauvinist s.o.b. and in a sense he piqued my interest in physics because he kept trying to be very discouraging...so that pushed me towards physics."

A third woman drew strength to pursue her interests from sources other than family or her own faculty.

"I have very good memories of my undergraduate experience at University X, but very few of them have to do with math. There was not an ounce of encouragement or acknowledgement from the faculty. I got more encouragement from two junior faculty at another university where I took courses than I did from any of the faculty at my school."

Influential Persons: The women who talked about influential persons or mentors in their life were talking about more than just faculty-student interactions. These interactions were purposeful and supportive to the women and they went beyond helping strictly with academic matters. The importance of building personal relationships with faculty is evident in the women's comments. Their recollections hold favorable, enriching memories that had obvious effects on the woman's decision to go to graduate school.

"One professor took me under his wing. When I was having a hard time he'd encourage me. And even now he just sent me a card to let me know he's thinking of me and wishing me well, and that was really important to have someone behind me encouraging me to go on. Just letting me know I had potential even when I ran into roadblocks like not doing well on a test,...that was okay, I really had potential to do this. That was probably the most beneficial thing."

"I had one female faculty member who really encouraged me. I was starting to have theories about the way things were taught. She was very descriptive, made things seem fun and wasn't into all this competition you feel in a lot of classes."

"Even though there were more women there [in a social science department], I found it harder to be a woman [there] than in math and I would credit that to one woman in the math department. She's not a faculty member, she's an instructor; because she's not a researcher, she's interested in education, in women, in students.

She was so seminal in terms of creating my experience in the math department and I'm very lucky to have had her there. I notice her absence here. Not that she did anything in particular there, just, you know, she knew when my mid-terms were and would say, 'so, how's it going?' and it didn't matter what I have done. The fact that she knew, and when I'd look sick she'd give me a cup of tea and for some reason that's all I needed. She didn't help me with my math...I really notice she's been gone. And the other thing is that because she's such an outgoing woman in the department, she really infused a sense of humanity in the department, particularly humanity toward women, but I think toward everyone, that other faculty picked up on. I was really impressed with the faculty members I had maybe not even had contact with who were interested in what I was doing and where I was going, had things to say and wanted to be part of the process and I feel that was very much because of [her] interest in encouraging women and making faculty members realize that being kind to someone has enormous value."

Although women noted the presence/absence of female faculty as role models in their fields or departments, it did not keep them from applying to graduate school, provided there were other sources of support and encouragement.

"There were only three women mathematicians at my university, two of whom were in statistics and the other in math education, [I] had no real role models. But I did well and I was encouraged and I'd always known I would go to graduate school or medical school."

"There weren't really any female role models. Only one tenured woman professor in math and I never had her for a class. A few professors were [encouraging] and I did well."

Decision to Go to Graduate School: For many women the decision to go to graduate school was a passive decision- making process. In general the mathematics graduate students decided to go simply because it was the "thing to do" whereas the physics graduate students went because they did not see what they could do in the field without a graduate degree.

"I'm not really sure of my reasons for attending graduate school. The problem with physics is there's very little you can do with just a bachelor's. If you want to research, you have to get a Ph.D., so that was a major impetus as to why I'm in graduate school."

"I grew up in a college town and graduate school was in the air. All my friends were in graduate school and now I'm here."

"I was in math because...it was certainly not something I felt a calling for...but when it came time to decide what to do next...by that time I have seen enough math to realize that I enjoyed math and I'd also seen there's a sense of making a point, too."

"Everyone was going to grad school. It was sort of expected. I took three years off because I knew I wanted to go to grad school but I wasn't ready."

"As a senior I thought it was fun to study physics...it seemed like the only option was to go to grad school. You can't really do anything in physics without graduate school. It was almost a given."

"I came here because someone in my home country came to this same program before. My company sent me."

Competition: All but one woman in the focus groups emphasized the rigors and demands of a competitive environment. Their comments also reflected feelings that competition is alienating, unfeminine, uncomfortable and often distressing. One woman, who came to the United States for her graduate training, gave her perception of how competition feels in U.S. schools,

"The system of education in the U.S. is much different from my home country. Here everyone is so competitive. There we study in groups, share everything, don't care about grades. Here, it's different."

Other women commented,

"It's really hard here because it is so competitive. They've set up these standards of what you have to do to be in good standing for money for next year. As I go on, I'm finding that the standards are more and more difficult to reach in terms of the classes you have to take and the grades you have to make."

"Sometimes it seems that the system of grad school is based on male attitudes of competition---sink or swim. The alpha courses in math, the first year courses, ended up being very competitive. . Some people just rise to the competition and the kind of person who rises to the competition tends to be male."

"I really did well last year, objectively. I rose to the competition last year, and I did want to beat out these guys who always were trying to figure out who got the highest grade. But I didn't like it and I was embarrassed that I did what I did, that I did feel competitive. But I felt sick and I never told my exam scores to anyone. Whereas they [men] seem to get a kick out of this whole thing."

"I've never heard a woman in the first year class ask anybody what their score was on a test."

"It's kind of paradoxical: in order to be in graduate school we have to be more competitive than the average woman."

"Sometimes I'll be competitive just to show up the men, but it makes me feel very unfeminine when I feel that way."

"I don't feel the sense that we compete in classes. But we have no choice but to compete with each other for research positions."

One woman saw cooperation among students as the backbone of her educational experience in graduate school.

"What has enabled me to get through has been the cooperation among 'first years' [which] is phenomenal. It keeps me sane."

Negative Qualities of Graduate School: When students described their expectations for graduate school, many of their responses focused on disappointments, frustrations and negative characteristics of their educational experience. One of the disappointments in graduate school was the lack of good teaching. One of the students who commented said,

"The teaching in the department is exceedingly poor."

Another source of frustration for these women in graduate school is their own performance as teachers. It worries them when undergraduates are not getting the best teaching because they, as teaching assistants, are overloaded with responsibilities. These graduate students are concerned about losing the opportunity to do their best in their courses because of being vastly over-extended as TAs. This theme is expressed as a conflict in the priority given to two very important roles of their graduate education: being teachers and being taught.

"The teaching that we have to do is kind of a negative experience. I was bad my first year. I know I was and I had never taught before and it was a big emotional drain to go in and do a bad job when I knew I was working very hard preparing and putting time into teaching and the students were reacting negatively because they knew I wasn't doing a good job. I worried more about teaching last year than my classes."

"They make us teach the hardest classes...in some ways."

"We're the main teachers; do the exams, give the grades."

"I don't mind teaching, but I'm teaching four lab sections and taking three courses. That to me is not a manageable load and supposedly that's a half time teaching position, but it isn't for anyone I know."

"I'd like to spend a lot more time preparing for my labs but it's the last thing on my list so I don't spend much time at all. I have only so much time to put into my courses, and so much time grading, and so much time just teaching the lab."

"It feels so terrible to do a bad job [teaching]. You feel like you have an obligation to these students because they're paying tuition here and working hard in class and...we're supposed to be spending 20 hours a week on teaching. I'm doing a bad job. It's something [at which] I'd like to do a good job...it's personally frustrating."

"Twenty hours a week...it's just not reasonable."

"They expect you to spend 20 hours a week on your teaching and even if that's enough time, it doesn't leave you enough time to do even an adequate job on your classes, which is why you're here."

A number of women also expressed great concern about qualifying exams and a fear of failing in their program.

"I went in thinking I'd be here for 4-5 years then leave. After a certain amount of time you see that every year 40 people come in and only 6 go out...I started to realize that [those] people didn't pass their qualifiers...and the next thought was: that could be me. Last year was complete anxiety and everyday I was thinking I might be kicked out. I passed one qualifier, but I'm still not even through the first stage."

"That's funny because my fear is just the opposite, that everybody's going to sit there watching me fail and nobody's going to say, "you're not going to make it, just leave."

"I hear people talking about students that they think should leave."

"I'm really worried about having wasted how [ever] so many years when someone out there knows that I shouldn't have bothered. That's my big fear."

<u>Positive Aspects of Graduate School</u>: Most positive statements made by the women in this focus group described the physical or emotional environment within their departments. They reflect a common need for social connectedness and professional nurturance, and the importance of linkages between these women's personal and professional identities.

"The department is very friendly. I've gotten to know people fast. There are parties, frisbee games. The faculty, some faculty, also come to the parties. The offices and classrooms are on the same floor. I didn't have as much contact as an undergraduate as I have now."

"I feel the same. I've gotten to know people well. I don't feel I know faculty as well."

"I've had a positive first year experience that I think is very unusual. I have had a professor actually take a personal interest in me. And I've sort of been able to develop sort of a relationship with him. We can talk about things other than mathematics. We've talked about art and he's willing to write a letter of recommendation for me...I haven't heard another first year student describe anything like that...Its been very good for me."

"I've gotten to the point where I can go to seminars in my field...usually I don't understand things, but its reassuring that most of the others don't either. The logicians, at any rate, are very social. At least once a month, and often more, one of the professors will have dinner at their house after the seminar and they bring their families and they bring their wives and they bring their current boyfriends or girlfriends...and people sit around and talk about politics and everything. It's very casual; it's good."

"This isn't really a positive experience but it's a good thing to say about the department. When I was thinking about where to come, I chose Michigan in the end because it seemed the most human of all the departments I saw. I found more socially well-adjusted people than at any of the other math departments I visited. I was impressed with the number of faculty members who came and spoke to me when I was visiting, who really seemed to take an interest in students as people and in the students themselves. I've found a lot of people here who said the same thing to me. I came here because it seemed like I could be happy here, not necessarily because it was the best department or it had a faculty member that I had to work with. But because it seemed like a pleasant place to be. Whether it's as pleasant as it could possibly be, it certainly is not."

"I'm not sure if people realize how important physical structure is. For instance, the women's room in the math building at the college I went to...it wasn't like we all used to hang out there, but it was a nice place to go. You'd see everyone you knew there...and the men would say "what do you do in there'. Someone saw the sofa in there...and it was sort of this bonding among the women...'yeah, we're gonna go hang out in the women's restroom'."

Size of the Undergraduate School: In general, the smaller the size of the undergraduate institution or department from which these women came, the more attention, encouragement and support was given to them. In small departments women had the opportunity to have the same professors for many classes and to develop relationships over time. Some women clearly felt at a disadvantage at a larger institution.

> "I think part of the problem of a big university [is] you don't have the contact."

> "I think there were points where I might have enjoyed my classes more [at a smaller school]. I think I might feel more confident now."

> "I went to a very small college...I got the impression that everyone was concerned with students, not just one faculty member. We all knew each other."

> "I went to a women's college...it is very small, all the faculty knew me. So, it was certainly a very supportive atmosphere for being a woman in science."

Two women describe experiences at large universities that made their largeness more or less manageable and comfortable.

> "Even though I was at a big school, I was in a very small select group."

> "I think it's important that you feel like you're part of a department. When I was in college, I didn't feel...well, there the math building has three stories underground and ten above ground and all the classrooms were below ground, then there's essentially no first floor, then the offices start on the second floor. You're not anywhere near the math department. You sit in class and you don't really talk to anyone in class, you get to know a few people, then you leave. So, you don't feel like you're part of a department [or] even that you have a room just to sit in and talk to people."

Gender-Related Attitudes and Experiences: The topics of sexist attitudes and gender-related issues came up at the end of the focus group after the moderator asked several times if there were "any other negative experiences?" The women appeared somewhat reluctant to address these topics. Yet when discussion did begin on this topic, many of the women described encountering negative and stereotypical attitudes toward women, while some reported positive experiences with colleagues.

> "For the first time, I was faced with a man who seriously had problems with women in mathematics and he was a fellow graduate student, not a faculty member. I got so fed up with him, I finally told him that I did not appreciate his comments, that I did not

appreciate his attitude, if he, well I couldn't make him change his attitude which is really what I wanted to do, but I told him if he didn't stop saying these things that were really demeaning and really patronizing that I would stop talking to him. He stopped talking to me, so that solved that problem. But it was the first time I had heard people, I mean he made a comment like "anything named after a female mathematician can't be that important." God, even just talking about it, makes me...and comments about girls and women as sexual objects like that. I didn't expect to have to confront that. With my professors maybe, but not with people my own age in graduate school."

"I've actually found first year men to be less open-minded than I would have hoped and...these are the people that presumably I could have gone to college with. Kind of a whole new generation of men from nowhere. I find a lot of...all of a sudden much more of a sense of women in math are different from people in math. It's not women and men in math together, it's men in math doing something, women in math doing something sort of different."

"This one person who I really think is a great guy, we work together and I thought I had his respect. The other day he really thought he was paying me a compliment. He said, 'You know, when I first met you, you [were] wearing big, huge earrings and you had long hair and I thought you were really stupid and shallow, but you're not and I just wanted to tell you that.' The way he said it I could tell he really wanted to to tell me this because it would make me feel better."

"I like to dress nicely when I go to school and wear feminine clothes. But every time I do it I think, now, when I walk into a class will the professor and the male students notice how I look and forget that I have a mind. Not necessarily that they're going to go 'wow, she looks really sexy today,' but just that I look different because I'm wearing a skirt not pants or I'm wearing earrings."

"I've had people ask me if I 'dress up' for a seminar, which I don't. It just happens that some days when there's a seminar, I'm wearing a dress or I'm wearing a skirt if I'm going to dinner at a professor's house. I want to look at least reasonably nice."

One woman made a comment about how difficult it is for women who decide to wear something besides blue jeans and a sweater. Another woman responded,

"But I don't think there's the same feeling of sexuality attached to it, or gender. For a guy it's just, 'hey you look nice today.' For a woman it's as if, 'you look nice today, therefore you can't do math today'."

"In [my] department, among the first year grad students I've found all the men to be great. They're really accepting, we work together."

"Talking about your experience with male chauvinists or whatever you want to call it. In the U.S. I've never met a physicist who thought that simply because I was a woman I couldn't do physics, who doubted a woman's ability. But I did run into that rampant in a European country. American physicists, in general, take you at face value. That's very reassuring."

"It seems to me sometimes that a lot of professors in the department are trying hard to be non-chauvinistic. They got their doctorates at the end of the 1950's. There's only one tenured woman in the department and I think that a lot of them don't know how to deal with women like that. A very famous woman mathematician came to visit a while back and the professors all seemed jealous of the fact that the women in the department, including instructors and women on temporary appointments had a lunch with her, and no men were invited...they all resented it."

"There was a lecture today in which a history of some mathematical theory was traced out and there were about 25 mathematicians listed. This mathematician was the only woman, she was the only one whose name was listed with a first initial, and she was the only one who was referred to by her first name. Everybody else...Maxwell did this...but, Karen has done this. It demeans her in a sense. Now it's possible that this man knows this mathematician personally. But, somehow, given who she is, I seriously doubt that he didn't know any of these other mathematicians and he happens to have a personal rapport with the woman mathematician."

Individual Themes of Focus Group One

Although the following comments reflect the concerns of only one woman or a small number of women, they are included because of their unique perspective on high school, undergraduate and graduate experiences.

A few women spoke about the importance of factors other than exams and classes in reflecting their potential to achieve academically and in contributing to self-esteem.

"In college, if you did poorly on an exam, there were other outlets, other ways to show that you did have a brain and that you could do [the work].

"Just letting me know I had the potential even when I ran into roadblocks like not doing well on a test that that was okay, I still had potential to do this. That was probably the most beneficial thing."

"When you start off at a new place, how can you convince anybody that you have potential when you're doing poorly in your classes?"

One woman commented upon teaching methods in math which in her experience employed passive rather than active processes for learning.

"Even in other classes like history, you're talking in classes...in history, TAs go out of their way to involve you. And I never had that happen in math."

Another woman reflected upon her view that no matter how well a woman does in mathematics and the sciences, someone will always be surprised that she has chosen it for her career.

"And I was remembering that in high school...I was very active in math teams, had a great time. In fact, I won the school math prize all four years, still when I go back to my high school and tell my teachers I am in math, they say "oh really? Yeah, I guess you were sort of good in math'."

One student described an experience that gave her valuable experience and confidence:

"When I was in college, one of the faculty members that I was really close to decided that the undergraduates should have a seminar where each quarter we would each choose a topic, research it, and give a presentation on it. I did that for four quarters. That was really interesting and it gave me my first experience in getting up and working on a chalk board in front of people which...I want to be an academic, so I'll have to teach."

Women have historically been much better represented in the mathematics education and actuarial mathematics areas than in pure and applied mathematics. This is clearly the case at the University of Michigan (see Table 1). This may be linked to the stereotypical perception that women are less capable in mathematics than men.

"The point was that the women in math at University X, by and large, are barely in math. And that seemed like a worse message to me. It's one thing not to have women, but to have women in a lesser capacity. And I had a roommate who was in math and had never taken any of the hard classes and in fact, while I was moaning and groaning and could have been so many other majors and been so much happier she said, 'I became a math major because it was the easiest degree to fulfill and it was if you structured [it] in that way and I think that's partly a flaw of the math program. There's a slow track in math that a lot of women take and I think they might nudge themselves up to a higher track if that was their only math option."

Common Themes of Focus Group Two: Advanced Graduate Women

The women who were in Focus Group Two were farther along in their program (the norm was the third year) than those in Group One. Generally, the same common themes were apparent, but they were presented with less detail.

Encouragement and Support: In general, the more advanced graduate women in mathematics and physics made more favorable comments about the support and encouragement they received as undergraduates. This encouragement helped to lead them toward graduate study.

"My undergraduate experiences were pretty positive...faculty didn't say 'go, go, go' [to grad school], but they were positive."

"I had all positive experiences. Undergraduate advisors did more than just sign registration forms. My senior thesis advisor had just finished graduate school at Michigan...I could relate to him very, very well. It was a very positive experience. He encouraged me very much...he said, 'of course, you're going to go on in math' If anything, he discouraged me from other things."

"...I got a lot of encouragement and attention just because...everyone there was supportive and I was urged to go on, so I did."

"Here, when I visited, people seemed really encouraging and I saw lots of women doing math."

"I had a very nice professor who was really encouraging. A lot of people were very positive."

"I had a pretty good experience in college. When I look back, I see that people were intimidated and I could be one of the better students and because of that...I guess I was a bit blind to that...It was a mixed experience, but it didn't affect what I wanted to do."

"I had a lousy undergraduate experience: it sounds like the opposite of everyone. My university has a large math department but there were very few undergraduates. I think there were about 15 math majors my year. I think about three of us were women. I had some really explicitly discriminatory kinds of experiences."

Influential Persons: The women in Focus Group Two were asked, "From whom do you draw support, social or intellectual?" Some responded by saying, "office mates, advisor, housemates." Other women wanted to say more about what support meant to them in terms of quality and quantity of time.

> "I have support from my family. I don't have daily contact with them and really not much contact with them at all. But there's a very strong backbone knowing if I'm ever in need, they believe in me. There's a lot of emotional support without actually very much at all. I have housemates. We've all been living together in this house, it turned into a household, which was a very good thing for me. There's always someone to go home to. My boyfriend gives a fair amount of support though it's all by computer mail. My advisor is actually very supportive, now that it's relaxed to a point where we know and trust each other."

> "I feel the same way about my advisor but I have no role model. I look around and there's only one woman in the Physics Department and I don't know her very well...so, I don't have any role model to build on and to know what happens after you graduate. There are a lot of social problems because I don't have a social life. I don't have a life besides grad school. We are all geeks because we study. Socially, I have no support, not many friends. My family is supportive but they always assumed I would do well in the academic way so they also say, "why aren't you more this, [why] aren't you more that?" So, I have the support of my best friend and then my mentor but I really don't have anyone I can go to and say, 'There's this problem I don't understand.' Also, I have no time to sit down and talk with the other person."

> "In the Math department there's the liaison committee that's a different kind of support. A group of students who meet once a month...It's sort of like once a month you can talk about things and maybe something will come out of it and maybe not, but it makes you feel like other people have the same..."

Decision to Go to Graduate School: Many individual women discussed their decision to go to graduate school. As with Focus Group One, this decision was more a passive than an active process.

> "I was originally a physics student as an undergraduate. At some point I decided that I just wasn't interested in physics and I enjoyed my math classes...so I thought maybe I should do something about this and so I decided to apply to math programs. This was the best place I got in."

> "If you're a math major, not much else to do [except graduate school]. Most people I know go to graduate school."

"Most people from my college go to graduate school. I majored in psychology in college. I taught for a couple of years and while I was doing that I thought, 'Well...maybe I'll do math'."

"After completing my education [abroad], I was unemployed for five years. I had to wait six years to leave the country. I guess I came to Michigan because I was too afraid to apply to better places,...so I came here."

"I really don't remember anyone encouraging me to go to graduate school. I just assumed I would go."

Several women also discussed their selection of the University of Michigan as their graduate school. Among other factors in selecting Michigan, it is interesting to note that they took into consideration the reputation of the program pertaining to the treatment of women.

"And I like teaching...but, I wanted to do something else. So, I applied to grad schools. And I applied to a bunch of places and I got into a bunch of places like Berkeley and Columbia and Yale and these places, but I was too scared to go there because I had a really lousy experience. I don't mean to say Michigan's not good, because I truthfully think it's as good. If you do it right. But I was just too intimidated to go to the others...anyway...it's weird because a lot of people at that university do go to graduate school, but nobody ever asked me and I really didn't hang around with the math majors because they were just different. I just didn't know about grad school somehow. And then later on I figured out...my other friends who were in classics and such, they were all going to grad school next year, and I thought, "I should be doing that, instead of working 9-5. So I came to graduate school."

"I didn't know I was going to go on in physics until very late in my career. Also, sort of strangely enough, it didn't occur to me not to go to grad school either. I don't remember going on to graduate school as being a major decision in my life. It was just kind of one of those things--well,...the big thing was, am I going to get these applications in on time? All the paperwork. Getting things in on time and the paperwork are really more hurdles than the academic things they throw at you. I went to Michigan because I did have such a spotty record; you can't get in everywhere you apply. And I did apply to a fair number of good places. But, I didn't get into any of them--I mean better places than Michigan. And they did give me money here."

"When I came to the U.S.,I really didn't know where I stood here. I was a very good student...the other thing was I had no information about American schools. I was encouraged by a woman mathematician to apply to Columbia, but I thought grad school and life in New York City just don't fit together. [And] all the stories I hear [about] Berkeley...that's the last place [for women]."

"I was trying to decide between Berkeley and Michigan. My advisor called a friend who had gone to undergraduate at Michigan and graduate school at Berkeley so she could compare. I was told the atmosphere at Berkeley was not all great."

Expectations of Graduate School: Participants' expectations of graduate school ranged from the very general to the specific.

"My expectations...I had a number of graduate student friends so I knew what grad student life was like. It's not that much different. The best part about it for me was I sort of went on blind faith that at some point I'd start understanding all of this stuff. And it's true, it does eventually start coming together for you."

"I came in fully expecting to flunk out. I was shocked because I understood everything. It was exciting here...I worked hard, but I was working hard because I was understanding. I was expecting it to be much harder, then I was really surprised. It wasn't easy all the time, but it was manageable."

"Perhaps I had really high expectations. I realized that in college everyone really cared about teaching. I took it for granted."

"I had no expectations. I came open-minded. It was hard work in the beginning."

Competition and Cooperation: In contrast to Focus Group One many women had cooperative as opposed to competitive experiences. This could reflect the composition of their particular class or their present status in their program as "survivors."

"I was expecting a very competitive atmosphere here. And I didn't [find it]; that was a nice surprise. Although I had a very hard time here my first semester and I found it very hard and I thought I would flunk. People worked together, shared ideas. There wasn't any of this dog-eat-dog attitude. I don't know how I got the idea that that's what it would be like."

"I expected much higher competition than what I found. We had a very cooperative class."

"I was not used to a study group. But people in my office would all get together and work on the same problem set. And I was beating my head against the wall, doing the work of five other people, because I wasn't in a group. After a few weeks the study groups really clicked...hard to get in and if you wanted to get out, you'd be really stupid, but you knew you could."

"I never worked in study groups. Is that more characteristic of females?"

"Yes. Men play baseball...they're used to groups, playing on a team. And we're not. We never had a real team-like relationship."

"Our class was cooperative, not competitive."

Negative Experiences: The participants had a variety of negative experiences and disappointments to describe and share. Many of these experiences centered on finding employment in their field as well as learning experiences within their disciplines. Women were disappointed because they had certain expectations when they began their programs and later discovered that these expectations could not be met.

"The bad experiences--it was difficult for me to find a job [research assistantship] by the first year. It was very discouraging. It worked out, but I was very angry my first year because it looked as though you could go through the program and actually not get a job in the summertime. For experimentalists it is just ridiculous. To go through an entire year and not actually be working in a laboratory is not my idea of...but the department is changing and is malleable, at this point. If you yell and scream enough and ask them for things. Everything that we have organized in some way and asked them to change...so that's been good to actually see some of the results."

"I think a lot of people are worried about the jobs [research assistantships] they're going to get. I was scared about getting a job after my second semester. I thought, I'm never going to find a job. I was too intimidated by the professors to say, "Look, do you want me?" I'd heard horror stores that they ask you all these questions and I don't know what the answer is ...you have to sell yourself, somehow, and how am I going to sell myself to a professor? So there was a lot of pressure and I think they're trying to make that easier. They're also trying to push people along as fast as possible."

"Sometimes I was disappointed in other students, when they had bad attitudes. They didn't seem to want to work. I don't know. Some people seemed to think it was a great thing if class was cancelled, they can go out and drink beer. But that was the one thing that, that's not an attitude that I've noticed in any women, actually. That seems to be a male thing...that was just an example...I didn't understand why they were in graduate school when they didn't seem to be geared up for doing math. They seemed to be here because it's the next thing to do or there's nothing else to do, so...I was taking these alpha level courses and there's all these people in there that maybe aren't really there for the right reasons, so that was the only thing."

"I think you learn a lot in classes. But one thing you don't learn is how to do it on your own. That was my big disappointment, when I went to grad school. I expected to be sort of working with a professor, which you do after a while. But when you first get here, it's 'Now go in that class with 30 people and do homework every single day.' It was very much of a grind and didn't have much to do with doing research. But the content of the courses...was basic information that you have to learn."

"I think most of them [professors] don't really care how they teach. They're here to do research. One of the major shocks when I got here was that they couldn't teach."

A couple of women thought that Michigan had excellent teaching and they interjected some brief comments.

"I think they really teach well here."

"We had great teachers my year."

"If you get a good teacher, it makes a difference. We do learn a lot. And, in our field, you have to learn so much...now I think the most efficient way is if you get a good teacher."

Other women saw their early experiences as survival tests and reflected upon just trying to make it through their first years.

"The disappointment was that faculty kept a distance at the beginning, like trying to figure out who was good. Not getting involved, but then there are a lot of us. The beginning classes are like boot camp--but, once it's over, it's much, much better in the third or fourth year."

"I learned I had to work day and night, night and day. At some point you have to think, "Is this all for the next five years?" I mean you have a life to live. There were no weekends. I was thinking that our experiences here are...there are no first year students here tonight, they're still struggling...I think they're very divergent."

<u>Gender Issues</u>: Some women talked about obvious gender-related, sexist experiences that they found disturbing in thinking about their role in science and achieving their academic goals. Such experiences tie into women's feelings of self-worth as well as into the values defined by a society that is often confused or ambivalent about its role expectations for women. It

was particularly interesting how some of these women wanted to communicate a different message to other younger women who will follow them.

"Please tell high school students that in physics you move heavy things, you get dirty, you do plumbing. There are things boys just know. You've just got to learn it. You have to ask questions. Part of it is being a foreign student, but there are still things that men know because their fathers taught them or they learned it in shop class."

"There's a lot of language that's completely foreign to me. Plumbing, electrical things. They're completely foreign to me, and I grew up in a reasonably progressive household. My mom did some of the plumbing, my dad did the cooking. Doing all these sorts of mechanical things--you really feel out of place in the lab when you start doing these things. At least I did; I think most women would."

"I learned at a conference--if you ask boys and girls if they've ever tried to fix something, boys say, 'of course,' girls so 'no'. But if you probe a little deeper and say, 'Have you ever tried to put your chain back on your bicycle?' they'll say 'yeah' but they won't see it that way-- girls don't perceive it as fixing something. This might have something to do with why there are less women in physics than math."

"It was also difficult to sort of integrate that human side. I don't know about math people, but we work in a lab and usually for 8 to 10 hours and we have lunch and we sit around and talk and so on. I found it hard to talk with men at lunch. If they were talking about physics, that was different. If they talked about men subjects like basketball, baseball--what do I know about these things? I'd just sit there and I then just asked them to teach me. Eventually they would teach me these things, but it was difficult at first to break down the barrier. There are some older technicians around the lab. They feel uncomfortable having a woman there--they tell jokes, not sexist jokes, not bad jokes, but they're jokes and I had a professor get so flustered because he had said something about someone and he turned around and said, 'At the time, she was trying to hide her gender, I mean her sex,' and then he said, 'Oh, that awful word.' And I said, 'It's okay, it's okay.' You have to teach them that a sense of humor is okay and you know as much about sex as they do. But it took some time."

"There's someone here who's from the university I went to who looks at me funny--like, "What are you doing here'?"

"I heard about someone at Dearborn who was told by a faculty member that she wouldn't make it in physics. She had gotten her bachelor's and master's and now when he sees her in the hall he sort of goes the other way. But I know him and he's such a nice person and I don't know why he would say something like that. My experience has been very positive, very positive. My own problems, whenever I don't understand something, I think 'Do men know this?', 'Is it because I'm a woman?', 'My past education?' But no one has ever really said anything that would make me think that."

Positive Experiences/Changes: In general, the women looked at disciplinary change, as a positive aspect of graduate school. Other students looked at the social or human side as the most positive part of their academic life.

"The department is changing and is malleable, at this point. If you yell and scream enough and ask for things. Everything that we have organized in some way and asked them to change...so that's been good to actually see some of the results."

"The new chair is good, so is the mentor, and they listen to grad students. He's very nice, very understanding, and he's made a lot of changes."

"So that was one of the things they explicitly changed and they guarantee funding for the first two years if you jump through the appropriate hoops. They also have summer programs so they will give you some money to make sure students have jobs in the summer. They also have a mentoring program."

"There was a lot of pressure and I think they're trying to make that easier. They're also trying to push people along as fast as possible."

"They also have a dinner program where faculty members are supposed to generate this random guest list and...they invite students and others. In our department a lot of the problem is you have no social interaction with people, it makes things cold. You don't know who to go to, till you're farther in the program."

Discussion and Conclusion

The dominant themes emphasized by both focus groups are consistent with other research done in this area. Comments are summarized here in general categories.

Encouragement and Lack of Encouragement: Both focus groups emphasized the importance of overt, consistent encouragement in their decision to pursue graduate study in math and physics. Most identified positive support with a particular person in their life--parents or a faculty member at the undergraduate level.

According to Lovely (1987), high school and college academic preparation is essential to women's and men's choices of science careers. But, for women, a second essential factor is the amount and type of encouragement and support they receive during the preparatory years. For Focus Group One, still very close to their undergraduate experience, faculty clearly played important roles in their lives. Faculty/student interactions that reached beyond academic concerns were especially important and demonstrated the faculty member's sincere interest in the welfare of the student.

This is consistent with what Ethington, Smart and Pascarella (1987) found about the undergraduate experience: women are influenced by the subjective quality of their courses and not just the academic nature or the intellectual content. "Affective aspects of learning", such as an interest taken in a student's career or helping to give some emotional support to the student, are important to learning in the sciences and the absence of positive educational experiences can affect a woman's plans for pursuing a science path in the future (Manis, Thomas, Sloat and Davis, 1989). Affective aspects of learning may also have an effect on a woman's self-confidence which in turn reflects her perceived ability to do well in mathematics and the sciences (Meyer and Koehler, 1990 and Lenney, 1981). Lenney (1983) speculates that women might actually be more vulnerable rather than just having a low sense of self-confidence.

Some women overcame strong discouragement to study mathematics or physics because of enormous support from significant adults, especially parents who held advanced degrees and/or were in the sciences. Research shows that supportive familial background is common for women who go on in the sciences (Ehrhart & Sandler, 1987; Meisel, 1983). In fact, families may be the only positive scientific-career influence for the women who have negative undergraduate experiences in scientific fields. "Having such a [career] goal apparently helps to counterbalance the negative impact of other factors, such as the competitive classroom atmosphere, or uncertainty about one's mathematical abilities" (Manis, Thomas, Sloat and Davis, 1989). Parental support appears to be essential for those women choosing non-traditional careers (Fitzpatrick and Silverman, 1989).

Studies indicate that women need more supportive mechanisms in their academic environment than men do. Perceived stress was the strongest predictor of assertiveness and self-confidence. The quality of the female student's advisor was positively related to assertiveness and self-confidence (Stansbury, 1986).

Many women in the focus groups had supportive advisors in their undergraduate years. Some women found supportive faculty in graduate school and, if not, they missed the presence of those positive role models/ mentors/ advisors.

Outside classroom contact with faculty seems to be critical for survival in graduate school, particularly if other factors, like the competitive academic climate, are working against women in the sciences. Becker's (1981) study of the differential treatment of female and male students in mathematics, found that the female students were called upon less often than men. Also, they were responded to less favorably than men and received less in-class reinforcement from teachers. To counteract this chilly climate inside the classroom, women may need greater positive interactions outside the classroom. Stansbury (1986) recommends that departmental communications be improved, especially between advisors and advisees.

Type and size of undergraduate school: The type and size of undergraduate school attended also has an influence on women who pursue graduate school in the sciences. Graduates from women's colleges, and from colleges with a high percentage of women faculty members, go on to graduate school and earn a proportionately larger number of doctorates in science than do the graduates of public, co-educational schools (Oggins, Englehart & Brown, 1988). One woman in Focus Group One explained her experience at a woman's college,

> "...it is very small, all the faculty knew me. So it was certainly a very supportive atmosphere for being a woman in science."

In the focus groups, the women who went to smaller colleges or who came from smaller science departments did find their experiences to be more positive than the women who were from larger universities. One woman attributed this to the amount of contact a student has with faculty; the larger the university, the fewer opportunities exist for contact. The more contact time that is made available for students to connect with faculty, the greater the chance that faculty will be supportive to women students in scientific areas.

Competition: The competitive environment in graduate school is seen by many women as inimical to the teaching/learning process. In general, the women in Focus Group One felt that Michigan was too competitive and that the learning environment was based on "male attitudes of competition---sink or swim." Other women, in Focus Group Two, saw the learning environment as generally more cooperative. Possibly competition is more stressful to women students in the early phases of graduate study. Perhaps programs should be structured to lessen students' anxiety about competition and to foster a more cooperative academic environment.

Horner and Shaver (1969, 1976, as cited in Rosser, 1990) tell us that "women learn more easily when cooperative rather than pedagogical methods are used." Programs that help women thrive involve the development of a cooperative, supportive atmosphere and team-building approaches to learning. Eccles (1986, as cited in Manis, Thomas, Sloat and Davis, 1989) describes the best classrooms for girls as having low levels of competition and high levels of either cooperation or individual learning.

Several experiences at the University of Michigan were described as "negative" in these focus groups. The fear of the qualifying exams, the anxiety produced by the "closed door" decisions made by faculty about student continuation, the overloaded teaching assignments for the graduate teaching assistants, and the quality of teaching and large class size were those most frequently mentioned. All these factors, separately and/or collectively appear to place a heavy burden on graduate teaching assistants who are expected to teach undergraduates effectively, as well as to perform satisfactorily in their own courses and, in some cases, to teach each other.

Summary

The amount and type of contact that is related to a woman's academic pursuit in the sciences, makes a very real difference in her self-confidence and success. The Focus Group women who felt best about their undergraduate experiences were those who received positive support and encouragement from family, friends and teachers. Even the women who had discouraging experiences with teachers were able to rebound, provided they had positive support from parents and friends.

Many Focus Group women expressed dissatisfaction with the competitive teaching and learning environment. Competition in learning environments did not fit most of the women's ideas of the best way to learn difficult material. In general, an ideal pedagogical experience for women is a supportive, collaborative environment where classes are small, the quality of instruction is high, and professors take an interest in each student's growth and development.

It is important, also, to provide appropriate forums for women to share concerns about their future and about gender bias in academe. Faculty and administrators need to be encouraged to be receptive to these concerns and to eliminate any vestiges of gender based discrimination.

E. Conclusions of the Three Studies

Our three University of Michigan research projects provide snapshots at varying points of time along the road to advanced educational training in mathematics and the physical sciences: initial entrance into the accelerated undergraduate curriculum; graduation with a bachelor's degree in mathematics or physics; and doctoral work within mathematics or physics. The previous discussions have focused on each stage separately. In the following section we will emphasize the quasi-longitudinal nature of our work and the apparent gender differences at each stage.

Undergraduate Level

What distinguishes the potential undergraduate mathematics/science concentrators from the actual mathematics/science concentrators? Indeed, who are the potential mathematics/science concentrators?

We saw little difference in high school grades between men and women entering the Honors Mathematics sequences (we will call this group the accelerated students) and no gender difference between the male and female concentrators. However, the students who actually graduated in mathematics or physics entered with somewhat higher average overall high school grades than those students who simply entered the Honors mathematics courses as first year students. At the same time, the mathematics/physics graduates finished with lower grades in their major (and also overall) than did the accelerated students. This can, in part, be explained by the traditionally more stringent grading practices within the mathematics and science programs.

Not only do academic abilities fail to strongly differentiate between potential and actual concentrators, but the students were not especially distinguishable by their individual behaviors in the mathematics classrooms. The accelerated mathematics students and the mathematics/science concentrators reported similar behaviors. The four most frequent behaviors--conquering something difficult, feeling that hard work paid off, studying with others, and asking questions in class--were the same for both groups, and were exhibited at nearly identical levels, with little or no gender differences. Males or females, potential or actual concentrators, these students reported doing similar things in their mathematics classes.

The most striking difference between the male and female accelerated students was the different choices they made regarding continuing mathematics study. While only 15% of both women and men completed the Honors mathematics sequence, the majority of the women (58%) dropped out of mathematics completely, while the majority of men (54%) elected to take non-Honors mathematics.

Both the accelerated students and the concentrators were asked to rate various facotrs which they believed to be important to their performance. Those factors deemed helpful by the mathematics/physics majors were comparable to the factors selected by the more diverse group of accelerated students. Just as with classroom behavior, the four factors of highest priority are identically ranked across the two groups--intrinsic interest, effort, natural ability, and quality of instruction--with males and females exhibiting almost no differences. The only difference between the accelerated mathematics students and the graduates lies in how helpful these factors are seen to be. While the rankings are identical, the mathematics/science concentrators consistently claimed these factors to be helpful, but at a lower level than that claimed by the students representing a broader spectrum of disciplines. Both groups cited the same three most harmful factors--understudying, academic anxiety, and the breakup of an important relationship--at comparable levels.

Despite the different choices made by students in Honors mathematics, some continuing on to graduate in mathematics or physics, others turning completely away from mathematics and the natural sciences, their behavior in mathematics classrooms would not have predicted their different decisions. Neither could an argument be based on differences in general academic perceptions.

There appears to be relatively little difference between the accelerated students and concentrators with regard to perceptions of gender influences in their respective programs. Approximately a quarter of the mathematics/physics concentrators, males and females alike, felt that a student's gender had an effect on their treatment in their program. Despite the wide range of concentration programs represented by the accelerated mathematics students, perceptions of gender bias were only somewhat more common among the women (one-third) and somewhat less common among the men (16%).

Both the female accelerated students and the female concentrators perceived less encouragement to pursue Honors course work than did the men. When the accelerated students were asked if a professor had taken a special interest in them, nearly three-quarters of the males, but only 58% of the females, answered affirmatively. And only one of the female concentrators who were informed about the Honors option responded that she had been actively encouraged to take Honors classes; nine indicated they were neither encouraged nor discouraged; fourteen did not respond.

Female students who began in the accelerated mathematics courses viewed a cooperative environment as having helped them and saw competition as a slight hindrance. The males also saw a cooperative atmosphere as helpful, but they saw competition as having little influence on their performance. This general gender pattern was also evident in the responses of the students who eventually chose to major in mathematics or physics.

Many more of the original accelerated mathematics students than mathematics/physics concentrators were intending to go on to graduate school immediately following college graduation (65% of the women and 74% of the men). Only 28% of the female mathematics/physics concentrators and 48% of the male mathematics/physics concentrators were intending to pursue additional schooling following graduation. This is in sharp contrast to the fact that the mathematics/physics concentrators entered college with higher previous achievement. It is believed that the unusually high percentages of former Honors mathematics students contemplating graduate school is a function of their participation in the overall Honors Program (true of almost all the Honors mathematics students) where students are part of a small community and all actively socialized into a more academic environment and more consistently encouraged to pursue additional post-college education. This socialization may explain not only the higher percentages, but also the reduced gap between males and females.

Among the mathematics/physics majors who were continuing on to graduate school, the men and the women had comparable college grade point averages, both overall and within their majors. However, the college grades of both men and women who chose not to go directly to graduate school were lower than those who did, 3.0 vs. 3.5.

Graduate Level

What is the situation for women who persist to graduate school in mathematics or physics? Do the influences which seemed important at the undergraduate level affect the graduate school experience? Do new factors emerge?

For graduate women included in the Focus Group Study the decision to go on to graduate school was often shaped by generalized expectations such as "my parents were scientists," or "everybody was going on," or "you just have to in physics." But the matter of where to go to graduate school was approached more concretely. Many specifically chose Michigan because it was seen as both welcoming and not impossibly demanding.

In contrast to the undergraduate, female mathematics/physics majors who saw themselves as not having received much encouragement, many of the graduate women, and especially the older students, pointed to parents or faculty members who not only encouraged them but fully expected them to succeed. These supportive connections seemed particularly characteristic of the women who came from the smaller undergraduate institutions.

Two influences which were seen by undergraduate women as detrimental were still causing trouble at the graduate level. Women in the Focus Group Study reacted negatively to any low-quality teaching they encountered, and many disliked competition when it occurred.

While the experiences and perceptions of the three groups seem more similar than dissimilar, it is clear that some factors were operating to encourage some women to persist in their schooling where others did not. Encouragement, whether by faculty, family, or peers, appears to be that critical link in the chain that helps build, or maintain, the self-confidence needed to continue along the desired path to a higher degree in mathematics or science.

V. RECOMMENDATIONS FOR FUTURE RESEARCH

Despite improvements during the past 20 years in the proportion of women earning degrees in mathematics and physics, the numbers of advanced degree recipients continue to be exceedingly low. Indeed, in 1989-90 in the U.S. only 158 women were awarded Ph.D.s in mathematics and only 129 in physics! Surely with concerted effort U.S. institutions should be able to at least double these numbers within the decade.

In order to significantly improve these numbers, more research universities must play larger roles. This will require concerted effort on the part of faculty and university administrators coupled with government, foundation, and corporate support for innovative research intervention and research programs.

A. Recommended Types of Research

Carefully designed research is needed to increase our knowledge of the causes of student attrition and to develop effective means of increasing women students' success and persistence. Particular needs include:

1. Longitudinal studies which follow students throughout the college years and beyond, and which, in part, emphasize the effects of pipeline and special programs.

2. National studies which include a large sample of women, including women of color, women who come from varying socioeconomic backgrounds, and women who attend different types of educational institutions.

3. Observational studies which analyze all components of the environment.

4. Exit interview studies of women undergraduates who pursued undergraduate majors in mathematics and physics but who chose not to continue on to graduate school, of women graduate students who discontinued their studies before completing the doctorate, and of faculty women who left the academy.

B. Recommended Topics for Research

1. Studies of the academic environment within the physical sciences and mathematics to explore the differential impact of the environment on men and women, and to determine which changes would be beneficial, and how to achieve them. These studies should address: the quantity and quality of faculty-student interaction, peer interactions and support, competitiveness, the physical environment, counseling, faculty expectations, discrimination and harassment.

2. Studies of instructional methods and course content to determine if they have different effects on men and women and their decisions to pursue science and/or mathematics.

3. Studies on the selection of subspecialties within a concentration to determine whether gender differences exist and, if so, why.

4. Studies of financial support patterns for men and women within the physical sciences and mathematics at both the undergraduate and graduate level.

VI. RECOMMENDATIONS FOR ACTION

A. Establishing Institutional Goals

The literature on women's achievement in the sciences suggests the convergence of a variety of factors which influence women's persistence and achievement in mathematics and physics. These factors include: the importance of encouragement and feedback from parents, teachers, and mentors; the negative effects of lowered expectations for women; the discouraging influence of poor and insensitive teaching; and the importance of connectedness and interaction with faculty.

Programs should be designed, whenever possible, to respond to factors identified in the research literature as potentially critical to women's success. However, we realize that due to the urgency of the problem, we must increase the number and quality of interventions in institutions of higher education before definitive answers to many of our questions are available. It is therefore imperative that interventions be thoroughly evaluated and that longitudinal follow-up studies of intervention programs be conducted.

Increased emphasis must be placed upon interventions at the undergraduate and graduate levels to target the many women who already have the necessary background and ability to succeed in nontraditional fields. Because of the large numbers of these women attending research universities, it is important for these universities to institute programs which will result in institutional change.

With these dynamics in mind, we recommend that mathematics and science departments establish the following institutional goals:

1. To increase women's interaction and connectedness with faculty to provide frequent, clear, and encouraging feedback.
2. To provide an interesting and challenging curriculum taught with greater skill and with more awareness of the environmental factors which affect women's learning.
3. To generate an academic atmosphere in which women are expected to succeed and in which sufficient numbers of successful women are visible at all levels.

B. The Process of Change

There is no reason to underestimate the difficulty of achieving fundamental change in institutions of higher learning. It will require a long-term process which starts with creating an awareness of the importance of a student's total academic experience. Thus, emphasis must be placed not merely on the content to be mastered, but the methods by which students are asked to master course content and the environment in which they are expected to learn. Both course content and teaching methods will need to be reappraised, and institutions will need to begin "warming" the academic climate.

Until the vast majority of faculty come to understand that a student's actual ability to learn is diminished by negative experiences, change will be superficial at best. And faculty will have little incentive to change as long as many of them believe that each student's academic success in science and mathematics is largely predetermined by innate qualities of dedication and brilliance.

Research seems to indicate that the students who are likely to succeed are those who (a) value and enjoy mathematics and science and (b) believe that they can succeed. The faculty's role should be to try to maximize both student learning and commitment rather than to simply locate those who appear to be the most talented and dedicated. In this way the pool of students who select science and mathematics majors and/or careers can be expanded.

C. Strategies for Institutional Change

Ultimately, increasing the numbers of women scientists and mathematicians depends upon the actions of academic departments and colleges. Outlined below are some steps departments and colleges can take that are designed to result in positive institutional change:

1. Systematically assess the present situation, collecting and analyzing comparative data on numbers and rank of women faculty, numbers of women students at each level, levels of available funding for women faculty and students, women's grade point averages and retention.

2. Systematically engage in departmental self-study to determine: which strategies succeed and which fail; which teachers are most successful in working with women students and why they are successful; what are faculty attitudes; why do women leave the program; what elements of the department climate are most supportive and which are not supportive.

3. Analyze the structure and content of advising to broaden the role of the advisor to that of advocate; train advisors to emphasize expectations of competence.

4. Actively recruit women faculty, graduate students, majors, and Honors program students.

5. Formalize regular means of providing feedback and encouragement to students (e.g. faculty-student conferences, written progress updates).

6. Ensure small class sizes so that instructors are able to give students appropriate levels of attention.

7. Use more experienced faculty to teach introductory courses; use outstanding faculty as master teachers. Restructure the faculty reward system to provide better incentives for teaching undergraduates.

8. Revise the curriculum to emphasize problem solving, model building and the discovery method.

9. Establish more collaborative classroom environments and grading practices; provide students with opportunities for team study with peers and/or more advanced students.

10. Establish regular mechanisms to sensitize faculty to issues of gender and pedagogy and the means of eliminating gender bias in the classroom.

D. Programs to Orient Women toward Graduate School and Mathematics and Science Careers

Research Internships

Most research internship programs have been designed to increase students' experience in conducting research and enhancing their knowledge of the discipline. While meeting these goals is important, internships may be even more critical for women for reasons other than the disciplinary knowledge and experience they provide. Because internships give students the opportunity to work closely with faculty, they are an ideal means of providing encouragement and mentoring, increasing women's self-confidence. At the same time they challenge students and impart needed career information and support.

We strongly recommend enhancing research internship opportunities, especially at research universities where opportunities for close interaction between undergraduate students and faculty are all too limited. While successful internship programs can involve a variety of designs (full-time summer programs, part-time placements during the academic year, paid internships, internships involving academic credit), it is essential to build into the internship the means of meeting women students' needs for greater knowledge about education and career paths. There must also be increased awareness of the need for encouragement and the building of self-confidence. As with teaching strategies, it is critical that means of increasing faculty awareness of the dynamics of gender be incorporated into the design of internship programs.

The timing of internship programs should also be given careful consideration. Internships are too often seen as rewards for already successful undergraduate students as opposed to a means of increasing student enrollment and persistence. In addition, timing may vary by discipline. While faculty may initially be skeptical about the ability of young students to contribute to research, our experience has demonstrated that laboratory science internships at the freshmen and sophomore years can be very successful and that this success quickly overcomes faculty skepticism. Involving students at this level is critical if their choice of major is to be affected. This is particularly important in physics where the number of undergraduate majors is extremely small.

The situation with regard to mathematics is somewhat different. Although there are far more undergraduate majors in mathematics, only a very small proportion of these continue on to graduate study. Hence, internships in mathematics might best be geared toward more advanced students with the goal of encouraging students to consider continuing on to graduate school.

"Pipeline" Programs

As mentioned earlier, there is a precipitous drop in mathematics enrollment at each level of the educational "pipeline." While an average of 7,475 women received bachelor's degrees in mathematics (47% of the total) in the years 1985-89, during that same period the average number of Ph.D.s awarded to women (18% of the total) was 131. There is evidence that women disproportionately elect job-oriented curricula. Thus, programs that encourage women to continue to graduate school are essential. Encouragement and preparation for graduate school should be a natural part of the counseling and guidance provided by faculty beginning with the first year. When this is difficult to accomplish (e.g., possibly because of reliance on teaching assistants), special seminars and programs should be implemented to forge ties between women students who show interest in careers in mathematics and science and faculty and counselors who can help them meet their goals.

Specialized Seminars and Summer Programs

In many institutions, the content of the physical science and mathematics courses are prescribed by the need to meet requirements of other disciplines. When this happens, the student interested in physics and mathematics often fails to see the breadth, power and excitement of that discipline. If non-service courses cannot be provided at the elementary level, departments should investigate providing freshman/sophomore seminars and/or special summer courses and programs where interested students could see this breadth, power and beauty and could pursue less structured, more individualized study. In the short-run for mathematics this may be the only way to expose elementary students to problem solving and mathematical modeling.

E. Conclusion

Our review of the literature and our own research studies suggest a complicated interplay between the many forces which erode women's confidence and undermine their abilities.

Although there is a national need for carefully designed research to steer the course of future programs, we cannot afford to wait for research results before beginning to implement institutional change. Each college and university can begin programs to strengthen the interaction and communication between students and faculty, to increase the numbers of women students and women faculty, and to revise the curriculum so that all students are engaged in thoughtful intellectual work.

We believe that the large research institutions, which educate so many women, have an obligation to lead the way. In the conclusion of his January 1990 address to the Sigma Xi Scientific Research Society, James J. Duderstadt, President of the University of Michigan and Chair of the National Science Board, summarized the challenge we face:

> *Time is running out. We have two major challenges to address: First, we must plug up the leaks in the education pipeline so that more students manage to make it through the gauntlet by majoring in science and mathematics. Second, over the long term, it is clear that we must reform the educational system, that is, completely rebuild the pipeline to respond to the changing world in which we live.*
>
> *In our colleges and universities it is time to think about improving what we teach, whom we teach, and how we teach.*

Appendix A: Carnegie Code

The 1987 Carnegie classification includes all colleges and universities in the United States listed in the 1985-86 *Higher Education General Information Survey of Institutional Characteristics.* It groups institutions into categories on the basis of the level of degree offered--ranging from prebaccalaureate to the doctorate--and the comprehensiveness of their missions. The categories are as follows:

Research Universities I: These institutions offer a full range of baccalaureate programs, are committed to graduate education through the doctorate degree, and give high priority to research. They receive annually at least $33.5 million in federal support and award at least 50 Ph.D. degrees each year.

Research Universities II: These institutions offer a full range of baccalaureate programs, are committed to graduate education through the doctorate degree, and give high priority to research. They receive annually between $12.5 million and $33.5 million in federal support for research and development and award at least 50 Ph.D. degrees each year.

Doctorate-Granting Universities I: In addition to offering a full range of baccalaureate programs, the mission of these institutions includes a commitment to graduate education through the doctorate degree. They award at least 40 Ph.D. degrees annually in five or more academic disciplines.

Doctorate-Granting Universities II: In addition to offering a full range of baccalaureate programs, the mission of these institutions includes a commitment to graduate education through the doctorate degree. They award annually 20 or more Ph.D. degrees in at least one discipline or 10 or more Ph.D. degrees in three or more disciplines.

Comprehensive Universities and Colleges I: These institutions offer baccalaureate programs and, with few exceptions, graduate education through the masters degree. More than half of their baccalaureate degrees are awarded in two or more occupational or professional disciplines such as engineering or business administration. All of the institutions in this group enroll at least 2,500 students.

Comprehensive Universities and Colleges II: These Institutions award more than half of their baccalaureate degrees in two or more occupational or professional disciplines, such as engineering or business administration, and many also offer graduate education through the masters degree. All of the colleges and universities in this group enroll between 1,500 and 2,500 students.

Liberal Arts Colleges I: These highly selective institutions are primarily undergraduate colleges that award more than half of their baccalaureate degrees in arts and science fields.

Liberal Arts Colleges II: These institutions are primarily undergraduate colleges that are less selective and award more than half of their degrees in liberal arts fields. This category also includes a group of colleges that award *less* than half of their degrees in liberal arts fields but, with fewer than 1,500 students, are too small to be considered comprehensive.

Source: Classification of Institutions of Higher Education with a forward by Ernest L. Boyer. Carnegie Foundation for the Advancement of Teaching, Princeton, N.J., 1987.

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