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SCIENCE

AAAS Presidential Lecture: Voices from the Pipeline

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The number of white males of college age, who have been the dominant participants in the fields of science and engineering, is predicted to drop significantly in the future. Rapid increases in the participation of women offer some hope of filling anticipated vacancies in the ranks of scientifically trained personnel, 'although this rapid growth has reached a plateau in many fields. Most studies show that women enter graduate school at about the same rate as men; the dropoff in women's participation occurs sometime before the attainment. of the Ph.D. Recent surveys of graduate students indicate that men and women respond differently to the pressures of graduate school and often have a different image of themselves and of their advisers' perceptions of them as graduate students. Some clues from these results may show how the en'ironment can be made more supportive for all students, and for women and minority students in particular.

AS PRESIDENT OF AAAS I HAVE CHOSEN THE OPPORTUNITY of the presidential lecture to discuss an issue in which I have been involved since the early 1970s—during a time of rapid increases in the number of women studying for scientific and technical careers. I have been actively involved in encouraging women to enter such careers and in helping to reshape the institutions in *which* these women find themselves. The issue of the full participation of women in science is at the very heart of the question of who will do science in the years ahead.

Demographic trends predict a future significant drop in the numbers of white males of college age, who have been the dominant participants in science and engineering. The likely effects of these trends on scientific and engineering personnel have been documented by the National Science Foundation and the Office of Technology Assessment (OTA) of the U.S. Congress. If current participation rates continue, the future pool of science and engineering baccalaureates is projected to show a significant drop (1—4) (Fig. 1). We have now passed the peak of U.S. graduate students available from traditional pools and are headed down the slope to a 26% decrease in the pool by the late 1990s. What is hidden in these statistics is that the percentage of minority students in this age cohort will increase substantially. Since this group is currently underrepresented in science and engineering graduate programs, a projection based on the current participation of various groups would show even a more severe drop in the production of scientifically trained personnel at the Ph.D. level.

In addition, the percentage of B.S. degree holders in science and engineering who attain the Ph.D. degree has fallen from about 12 to 6% over the past 20 years (1). In engineering, the number of Ph.D.'s obtained by U.S. citizens per year fell by more than 50% between 1970 and 1984 (5), and at present more than 50% of Ph.D.'s in engineering awarded each year go to foreign nationals (1). In science, the actual number of Ph.D. degrees awarded to male U.S. citizens has continually tended downward since 1970 (1). Increased competition between industries and universities for the reduced number of B.S. degree holders will likely occur. Indeed, this competition is evident already in engineering and is a major reason for the significant decrease in U.S. students attaining the Ph.D. in engineering.

These issues have provoked a number of responses from the scientific and education communities. The importance of precollege science and mathematics education for all children, with special emphasis on disadvantaged groups, has been stressed. The possibilities of influencing career choice at various decision points have been discussed. The climate for B.S. students in science and engineering has received much attention, as has the issue of discrimination in the workplace and its effect on career choice. Projecting future work force needs and availability is difficult, since slight changes in the participation rates can cause large swings in the data. Nonetheless, on the basis of current information, the composition of the graduate school population can be expected to change dramatically over the next two decades.

One of the most important offsetting trends in the projection of rapid decreases in scientifically trained personnel has been the rapid increase in the participation of women across all fields of science and engineering (2) (Fig. 2). This trend *offers* some hope of filling anticipated vacancies in the ranks of scientifically trained personnel, although this rapid growth began to plateau in many fields after 1985. There has also been a correspondingly rapid increase in the percentage of women in law, medical, and graduate business schools: women now make up 40% of the students in law school and 34% of the students in medical schools, and they receive 31% of M.B.A. degrees (2).

An OTA report (6) presented the pipeline issues for women students in the natural sciences and engineering relative to that of men in a dramatic way (Fig. 3). The report described an initial

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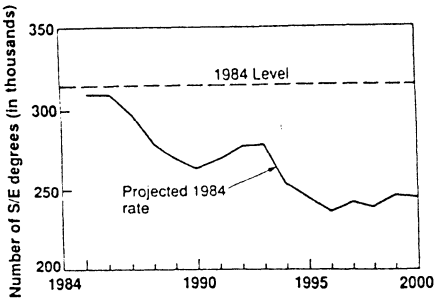

Fig. 1. Number (in thousands) of future science and engineering ( ) assuming 1984 participation rates (1).

cohort of 2000 male and 2000 female students at the ninth grade level. Of that original cohort, only 1000 of each group will have sufficient mathematics at the ninth grade level to remain in the pipeline. When the two groups are followed to the end of high school, 280 men and 220 women will have completed sufficient mathematics to pursue a technical career. A major drop in women students occurs with career choice upon entering college, with 140 men and 44 women choosing scientific careers. After a career choice is made, a larger percentage of women than men actually complete their intended degree in science and engineering: at the B.S. level, 46 men and 20 women receive degrees. Data show that women enter graduate school in the same proportion relative to their percentage of B.S. degrees as do men in the various specialities (7). (The number actually entering graduate school from each cohort is estimated from their current presence in graduate schools since entry data are not available.) However, some combination of attrition and stopping at the M.S. level rather than going on for the Ph.D. creates another major drop for the women students in the pipeline. Of the original 2000 students in each group, five men and one woman will receive the Ph.D. degree in some field of the natural sciences or engineering.

These results suggest that two points of concentration on the career aspirations of women students would be fruitful: at the career choice and during the graduate school years. Many studies and projects have been carried out on the point of early career choice; much less has been documented about the environment in graduate school and its effect on degree completion rates.

Beyond the issue of the health of the scientific enterprise and the necessity to make full use of the intellectual talents of all of ow population, there is the issue of equality of opportunity for these talented individuals. In addition, we should concern ourselves with the issue of future public support for science on the part of groups who perceive that they have been excluded from full participation in the scientific enterprise. The years ahead may be troublesome for the support of science, and the image of science as a community accessible to all will be important to maintain public support.

Graduate Student Surveys

Several recent surveys of male and female graduate students preparing for scientific and technical careers were carried out at Stanford University (8) and at the Massachusetts Institute of Technology (MIT) (9, 10). In addition to quantitative detail about differential attitudes, expectations, and experiences of these students, the wealth of comments from students provides considerable insight about the process of graduate education as seen from the student's perspective.

In the Stanford study, graduate students in medicine, science, and engineering were surveyed, with a 54% return rate for a total number of 627 students. The results were presented only for the combined group. The major conclusions of this work were that the

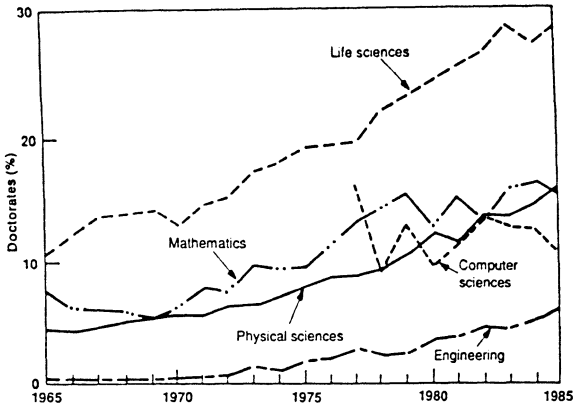

Fig. 2. Percentage of natural science and engineering doctorates awarded to women. [Sources: National Science Foundation and National Research Council, Washington, D.C.]

women were indistinguishable from the men in objective measures of preparation, career aspirations, and performance in graduate school. They differed significantly in their perceptions of their preparation for graduate study, in the pressures and roadblocks that they experienced, and in the strategies that they developed for coping with these pressures.

Graduate students at MIT were surveyed both by the Graduate School Council (9) and by the presidentially appointed Committee on Women Students Interests (10). Both surveys covered all of the departments in the institute. More than 1600 questionnaires institute-wide were returned in the first survey. Within the School of Science, 476 student questionnaires were returned in the second survey. The MIT surveys reinforced the conclusions of the Stanford survey. In addition, in both of the MIT surveys, the results differed widely across departments, including responses to questions focused on the academic environment for women students. Whether these distinctions are due to differences in fields, the different percentage of women students in the various departments , the personality of the departments, or specific policies and practices that a department uses to provide information and academic guidance to the students is not clear. However, the survey results indicate that for departments with a poor environment for women students, a few specific measures might lead to considerable improvement for all students.

Nationally, women enter graduate school at about the same rate

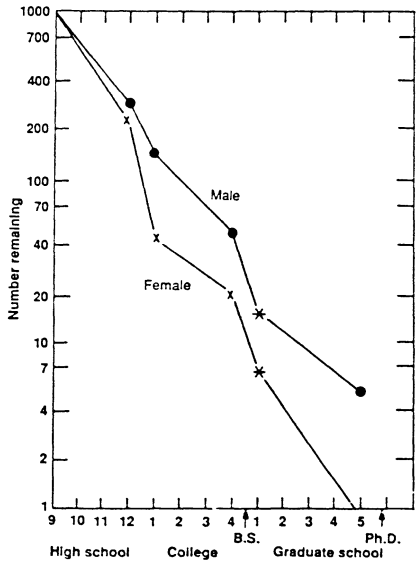

Fig. 3. Cohort remaining in the pipeline at various stages in the educational process in the fields of natural science and engineering from an initial group of 2000 ninth grade girls and 2000 ninth grade boys. Asterisks indicate estimates from OTA data (6).

as men relative to their presence in the B.S. pool (2). The career aspirations of women in the Stanford survey were the same as those of the men. Objective measures of their academic achievements and potential indicate that the entering women students were as qualified for graduate work as the men. Men in the Stanford survey scored slightly higher on the math section of the Graduate Record Examination, whereas women scored higher on both the verbal and the analytical portions of the exam and had a higher undergraduate grade point average. The grade point averages of the male and female students as graduate students were essentially the same (8). As a group representative of only a fractional percentage of the cohort of females of their age, statistics of large groups or preconceived ideas about their specific interests, attitudes, aptitudes, or commitments cannot be applied.

The drop-off in women's participation in scientific careers after the B.S. degree seems to coincide with the lower rates of attainment of the Ph.D. I have been unable to identify comprehensive studies of attrition from graduate school in science and engineering, but available data suggest that women often stop at the M.S. degree rather than continuing to the Ph.D. and that many more women report serious consideration of dropping out of graduate programs. Anecdotal information suggests that they do drop out at a higher rate than the men. Also, data indicate that a larger percentage of women students is to some extent self-supporting (2). Within a given field, there is a direct correlation between male female differentials in self-support and differentials in the time required to attain the Ph.D. degree. [The disparity in self-support is even greater for blacks (5)].

Graduate Education and Research

Education can be seen as a continuum, a progression from the development of career-related skills in a preset curriculum to the achievement of autonomous professional capabilities. However, it is at the graduate level that the student begins to function as an independent scientist—indeed, that is the purpose of graduate education. Ideally, graduate education should proceed from an explicit set of tasks—acquiring advanced skills through courses, preparing for and passing a set of qualifying exams to demonstrate mastery of one's field, and carrying out technical work under the close supervision of a faculty adviser—to the development of independence in the student. During this process the faculty gradually begins to remove the props supporting the student and to place more responsibility on the student for problem formulation, evaluation, execution, and defense. Ideally, as the process occurs, the student has access to a variety of structured professional experiences designed to enhance self-confidence and build independence. These experiences include opportunities to present and defend research results in regular and productive group meetings, to evaluate and criticize the work of peers, to formulate and carry out research tasks of increasing importance, to participate in dialogues and debates about scientific and technical issues, and to discuss future career plans as they relate to current interests and activities.

Faculty members often do not make these latter parts of the educational process explicit to the student. Much of the stress of graduate education results from a lack of student understanding of this hidden agenda. Students who duck such professional experiences because of a lack of self-confidence or because they find them painful are deprived of an important component of the graduate experience. Although they may be successful in achieving a Ph.D., they may not be equipped to take full advantage of the next set of career possibilities, and they are unlikely to be recommended by their mentors for important opportunities in their profession. Attention to how women and minorities are affected by and respond to this hidden agenda will be valuable in developing strategies to allow them to achieve their full potential.

To be successful, the graduate student must run both an academic and a financial support gauntlet. The academic gauntlet is the most explicit. Successful passing of graduate-level courses and various exams by specified deadlines are usually clearly laid out as requirements for the students. Less clear is the issue of financial support, the desirability of various forms, and the leverage that certain modes of financial support give to the success of thesis research and adviser interaction. The task for the student is to find a spot in a functioning research group, work on a topic central to the interests of the group with sufficient financial resources to carry out the research, and work with a faculty adviser who will both supervise the research and guide the educational and future career development of the student. The level of support required for this task is well beyond what is needed to support the student's living expenses.

A fellowship, while providing some flexibility in the beginning of a graduate program, may actually delay the acceptance of the student as a member of a research group. A teaching assistantship, while providing financial support and interaction with younger students, can also delay acceptance into a research group and offer less time for carrying out independent research. The research assistantship (RA) will facilitate the student's acceptance into a research group, provide a research topic central to the group, and allow access to resources such as equipment and computer time. The fact that a smaller percentage of women graduate students than men in all fields of science are supported on RAs (2) has serious implications for the quality of their graduate education.

Whatever goals the student had when the initial decision to attend graduate school was made, the process itself will continually act to reformulate these goals. The continual testing and trial of one's academic and personal characteristics, the ongoing interaction with peers and supervisors, and the signals picked up about one's relative potential within the research group will reshape the career goals and

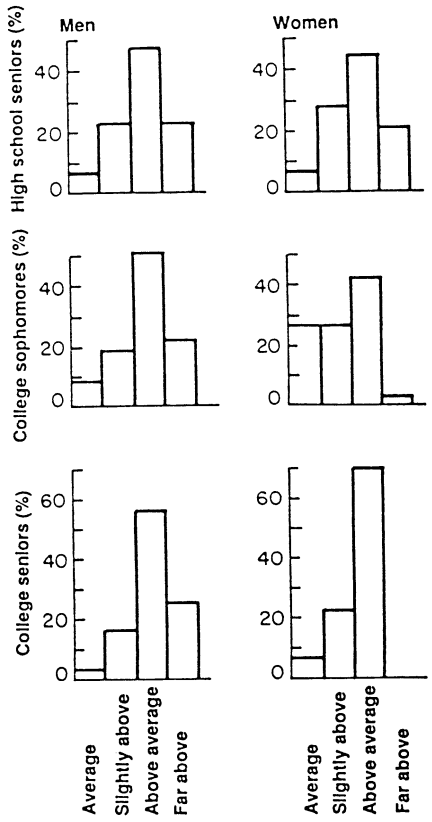

Fig. 4. Self report of intelligence as compared to peers (11).

affect the research productivity and career aspirations of the students. The research opportunities presented by the faculty and the quality of interaction and support will strongly determine the quality of graduate education and the preparation for further career advancement. A reasonable objective for the education of women and minority students is that they have a fair chance to succeed in graduate school; that the feedback loop of lowered expectations based on "sex or race, leading to lowered self-image and finally to lower performance, be broken by conscious action by faculty and students; and that the students be aware of the future consequences of career-related decisions.

Because the Ph.D. thesis is primarily an apprenticeship in research, the success of the graduate experience depends on the quality of interaction with the adviser. The adviser is the primary gatekeeper for the professional self-esteem of the student, the rate of progress toward the degree, and access to future opportunities. Problems with the adviser-student relationship are apt to go unreported by the student out of fear of professional reprisals. There are few checks and balances in the system, and the rest of the department faculty can do little to redirect an impaired relationship. Changing advisers after investing several years in research is a traumatic experience for the student, and it is likely to delay receipt of the degree considerably.

Our current method of financing scientific research and graduate education puts considerable stress on both faculty and students. The graduate students are the first in line to be-affected by pass-through stress from their research supervisors. The continued search for research funds and the continued high level of professional activity required to remain at the forefront of research make faculty less accessible to students. The graduate education process is labor-intensive, requiring large amounts of faculty time. Students are often aware only of breakdowns in the system: the neglect of the faculty, their inaccessibility, their failure to appear at oral exams, and their occasional unprepared lectures. The current system of support of graduate education makes it impossible for a faculty member to make a commitment of support to the student for the length of a typical graduate program. Gaps in funding are common, and students are often faced with the choice of dropping out or taking on a debt burden to complete their degree.

These familiar facts of life of graduate education are at the heart of much of the stress felt by all graduate students. However, the white male students benefit from the self reinforcing confidence that "they belong." The self-identification with the predominantly white male faculty reassures them that graduate school is a step on the way to a productive career in science, and that many others with whom they can identify have done it before them. For women students, minority students, and many foreign students, the environment is not as reinforcing. Their acceptance by the system is not automatic. Results from the Stanford survey (8) indicate that 35% of the men compared to 24% of the women were confident of "making it" in their chosen field; 62% of the men, but only 51% of the women, anticipated an academic career.

Results from Student Surveys

In the various student surveys, students commented on their personal experiences in graduate school. Most of the comments were complaints about the current system. There were subtle differences in the responses of men and women. The men most often expressed anger, even rage, at the system and suggested ways that it should be changed, whereas the women more often described the effect that the current system had on them and expressed feelings of frustration and discouragement. For example, the following comments were made by students from the same department when asked what hindered their graduate education (10) :

1) From a man: "The absolute insensitivity of the professors, department, and university to the inevitable depression experienced by young scientists when their research doesn't work so well. The . . . university's . . . willingness to ignore all graduate students but the . . . top 10% elite."

2) From a woman: "Despite denials, as a woman in . . . science . . . I had something to prove—and yet the most difficult part about it is that I don't know what it is or how to prove it. There is just the knowledge that I have at least one more test to pass than my male counterparts. Or maybe it's one more test to pass daily."

As revealed by student surveys, the issues affecting minority, foreign, and women students are related to their differences from the majority, their feelings of powerlessness, and feelings of increased pressure and isolation. For example, significantly larger percentages of women students than men students in both the Stanford and the MIT studies reported that the environment was detrimental to their health (8, *10).* In the Stanford survey, 23% of the women versus 9% of the men reported that they thought they were on the verge of a nervous breakdown. The data on minority students are too sparse to draw any conclusions, but it is likely that graduate school is an extremely stressful environment for them.

Women students are not a minority at the undergraduate level in our colleges and universities. Yet the effect that education has on them sets the stage for their minority presence in graduate school. Studies indicate that the self-esteem of women students is lowered in college, while the self-esteem of male students is raised.

The Illinois Valedictorian Project (11) was a study that followed a group of 80 students (46 women and 34 men) who had graduated in 1981 at the top of their high school classes. The group continued their high academic performance, with the women earning a final grade point average of 3.6 and the men an average of 3.5 for their college years. In spite of this objective record, when this group was surveyed at several points in their educational careers concerning their self estimate of intelligence relative to their peers, the results shown in Fig. 4 were obtained. The shift of self-esteem to lower ratings is quite evident for the women students. At the end of high school the groups were quite comparable, but females suffered a significant loss of self-esteem in the sophomore year of college. At the senior year of college, no women had a self estimate in the highest category, whereas 25% of the men did, even though the grade point average of the women was higher than that of the men. In contrast, the self-esteem of the men increased slightly during the college years. Even though women in science have degree completion rates above those of the men and cam' on to graduate school at about the same rate, these results suggest that they arrive at graduate school with some uncertainty about their abilities, even though their academic records and test scores are equivalent to those of the men.

A second trend noted in this study (11) was the lowering of career ambitions by the women students. The researchers linked lowered career ambitions in part to the unresolved dual-career problem: that is, the student's uncertainty about how to combine career and family responsibilities. One of the most effective antidotes for these uncertainties about career goals was the opportunity for successful professional experiences: independent research, professional employment, opportunity for interaction with graduate students, and the support and encouragement of a faculty mentor. Most women scientists of my generation can probably point to a single individual who was supportive at the undergraduate level without whose encouragement they would not have gone to graduate school.

Without such opportunities a woman student may carry through with excellent performance in classes but be unsure about her actual potential as a professional. She may also develop the well-documented "imposter" syndrome with its accompanying fear of eventu-

ally being "found out." This insecurity shows up in several ways. In spite of objective data indicating that women in graduate school have academic backgrounds comparable to their male peers, a significantly higher percentage of women in the Stanford survey (8) reported that their preparation for graduate school was inadequate. In the MIT survey (10), women students reported more difficulty in acquiring research skills. Whether these self assessment reports are true or represent women students who downgrade their capabilities is not clear from the data. The reports could also be related to the student's interactions with her research adviser. In some cases the process of acquiring research skills may be unconsciously set up for women to fail: women may be given too much help on easy skill-building problems (because it is perceived that they cannot do the work alone) and then are left to flounder on the more difficult problems. In the Stanford survey, 82% of the men and 73% of the women reported being satisfied with their programs; 72% of the men and 61% of the women reported that they believed they were progressing as well as other students (8).

For the women students themselves, as well as the departments in which they study, some serious attention to these issues is warranted. Objective discussions between adviser and student about the academic background required to undertake certain lines of research should take place, and ways to fill in any weak areas should be identified. Discussions of the expectations of the department for graduate student performance beyond the classroom, identification of objective criteria that should be met on the way to independent research, and some specific attention to methods of acquiring research skills are suggestions to deal with these issues.

Studies of objective evaluations of the potential and the accomplishments of women give quite discouraging results. Such studies in which male or female names are applied to resumes, proposals, and papers that are then evaluated by both male and female evaluators consistently show that the potential and accomplishments of women are undervalued by both men and women, relative to the same documents with a male attribution *(12-15).* I believe that graduate admissions officers are aware of this and attempt to correct for it in the admissions process, but I would be surprised if individual, hard-pressed faculty were immune from this behavior.

Lower expectations by an adviser, whether conscious or unconscious, are quickly perceived by the student. *This* perception may occur more often with women students, *who* need additional feedback because of their tenuous position. The student surveys show that women meet less frequently with their research advisers; a smaller percentage of women than men meet weekly; a larger percentage of women than men report meeting rarely with their advisers. Also, more women report that these interactions with faculty do not provide helpful feedback on their research progress. There seem to be qualitative differences in the type of feedback that some women students are looking for. To quote one woman from the MIT survey (10): "My adviser tells me whether it's right, not whether it's important." Women reported less frequently than men that they felt free to disagree with their advisers or that their ideas were respected by their advisers (8). The issue of barriers to effective communication needs to be examined by both advisers and their women students.

Many faculty socialize extensively with their graduate students through sports and informal get-togethers and may unintentionally leave out their women students or even suggest that they are unwelcome at such gatherings. Women students often conclude that this is a direct reflection of the quality of their research (10). Perceived lowered expectations lead directly to a loss of self-esteem and over time to a lower performance--a self-fulfilling prophecy. Women students give their advisers a great deal of power in assessing their ability, and women are apt to internalize and validate their perceptions of this assessment.

On all of the questions in the Stanford survey designed to elicit the level of self-confidence in the academic setting, the women students scored consistently, and in some cases alarmingly, lower than the men: 30% of the women versus 15% of the men questioned their ability to handle the work; 27 versus 12% found criticism difficult to accept; only 30% of the women versus 57% of the men felt confident speaking up in class; and 33 versus 9% feared that speaking up would reveal their inadequacies (8). In view of the importance of the hidden agenda that uses structured professional experiences to elicit independence in the student, some significant fraction of the women students is less equipped to seek out, to engage, and to profit from these experiences. Explicit attention to structuring positive professional experiences for all graduate students will improve the environment for women students.

In the Stanford survey, more women (20%) than men (6%) reported never having had major responsibilities within their research group (8). In both the Stanford and MIT surveys, women reported less opportunity to publish, or less frequently being the first author on publications (8, *10).* However, these results differed across departments, with the most encouraging results obtained in those departments that had high percentages of women students.

Environmental Issues

Women graduate students report being subject to inappropriate treatment by faculty and student colleagues. Inappropriate treatment in the context of graduate school is any treatment that emphasizes the student as a woman first and a student second. It is any treatment that stresses the social nature of the interaction rather than the professional or educational nature *(12-16).* Many women students report the necessity to continually fend off such inappropriate behavior in order to be allowed to concentrate on the professional issues of graduate school. This continual need to respond to such treatment can seriously interfere with the self-esteem and productivity of women graduate students (15).

Even today, there are still a few faculty members in science and engineering who publicly, or in discussions with faculty colleagues, take the position that women do not belong in graduate school. These individuals are at the least tolerated and seldom publicly challenged by their colleagues. Female graduate students quickly become aware of such feelings; although such actions cannot be attributed to an entire department, one wonders how such behavior can be tolerated in a university environment. It is particularly unfortunate if the individual involved would otherwise be the most appropriate adviser for the student on the basis of the student's research area.

Studies of group meetings involving men and women reveal that women are at a disadvantage with respect to male norms in groups (12-16). Women are interrupted by men much more frequently than are other men. A woman's contributions are often ignored or attributed to one of the men in the group. Many women students report discomfort at the combative style of communication within their research groups. Studies of men and women in group situations reveal differences in their modes of communication and tension in their intersexual interactions (12-16). Men often feel comfortable with a communication style that seeks to reduce one of the protagonists to rubble in the course of a scientific discussion. After the storm is over, they quickly forget about the incident. For many women this style of interaction is unacceptable, either as giver or receiver. A woman student may take weeks or months to recover from such an interchange, and it may contribute to a permanent loss of self-esteem. Women report that a process in which points are won

only at the expense of putting someone else down is to them an unacceptable mode of scientific debate. They are looking for a mode of interaction that is other than a zero-sum game.

Women students report being much less satisfied with the information available from departmental channels on issues such as the structure of qualifying exams and financial support policies. They also report not being as well integrated into the student network (where copies of past exams, for example, can be obtained). For access to such resources, the acceptance of women students as colleagues by their male peers is essential.

A disturbing percentage of women in the MIT survey reported that their gender is a significant barrier to access to academic resources (10). The quantitative results ranged from 16 to 30% across the various departments in the School of Science. This was true even in those departments where women students had high self-esteem. In the Stanford survey, 13% of the women (compared to 1% of the men) reported that the sex of their adviser had a negative impact on them; 40% of the women (compared with 30% of the men) reported having had some negative experience with faculty members, whereas 20% of the women (versus 7% of the men) reported experiencing some form of discrimination (8).

Women students have raised some fundamental issues about the quality of graduate education for all students. The continued drop-off in the percentage of B.S. degree holders who eventually attain the Ph.D. may be related directly to the current environment seen by graduate students. If we are to escape the projected dramatic decrease in the number of graduate students, some improvement in graduate education for all students is necessary.

With respect to improving the environment for women students, an increased sensitivity on the part of faculty to the seriousness of women as professionals and the willingness of faculty to structure the research environment to enhance self-esteem and provide positive professional experiences are the most important features. A willingness by the faculty to publicly challenge professional colleagues who make prejudicial or inappropriate remarks about women students would improve the climate. An effort by faculty to make the group interaction a positive-sum game for all students, while being no less insightful and scientifically critical, would enhance the graduate experience. The positive comments on the student surveys by both men and women reported the beneficial effects of such an educational environment. Such suggestions, if more widely followed, would improve the professional and human climate of our graduate schools for all students.

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