FEMALE FRIENDLY SCIENCE AND ENGINEERING

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During the last three decades, the population of the United States has become increasingly diverse; that diversity has been reflected in the changing demographic profile of students in higher education and in the work force. The work force in the year 2000 is predicted to differ significantly from that of today:

> There will be a larger segment of minorities and women: 23% more Blacks, 70% more Asians and other races (American Indians, Alaska natives and Pacific Islanders), 74% more Hispanics and 25% more women adding 3.6 million, 2.4 million, 6.0 million and 13.0 million more workers respectively. Altogether, the minorities and women will make up 90% of the work force growth and 23% of the new employees will be immigrants.[1]

This work force growth will occur in precisely those groups that have not been attracted in larger numbers to pursue careers in higher education, particularly mathematics, science, engineering, and technology.

Data collected by the Office of Technology Assessment reveal the loss of large numbers of individuals, both men and women from the scientific pipeline. These same data reveal the relatively dramatic attrition of women compared to men and the particular points in the pipeline where this attrition occurs:

> The report described an initial 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 technical specialties. (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.[2]

Closing the gap between the two cultures of white middle class men and men of color and women to attract the latter group to science will not occur simply by stating that more women and people of color are needed, although that statement may attract some individuals in a troubled economy. Attention must be given to curricular content and teaching techniques traditionally used in mathematics, science, and engineering to determine how they might be changed to be more attractive to the needed groups.

Two decades of women's studies scholarship and experience with curriculum transformation projects have enabled faculty to develop models[3, 4, 5] that chart the phases through which changes occur in a variety of disciplines in diverse institutions. Some studies suggest that similar phases are involved in incorporating scholarship from ethnic studies in the disciplines. This paper explores a model which examines how the composition of the community of scientists may be reflected in specific curricular content and pedagogical techniques through theoretical questions and issues deemed as significant from the perspective of that pool of scientists. Changing the curricular content and pedagogical techniques may lead to a different composition of the pool of scientists who hold a slightly modified theoretical perspective. This perspective may in turn be reflected in further transformation of the curriculum and teaching techniques. The ultimate end of this upward spiral would be a community of scientists representing the same diversity with regard to race, gender, class and sexual orientation as the United States population as a whole. Their perspective would be reflected in a transformed curriculum and methods which would attract scientists who might evolve an improved science.

Phase Model for Transforming the Natural Sciences:

Phase I. Absence of Women Is Not Noted.

Most science curricula are in phase I. In this phase faculty and students are not aware of the absence of women scientists in theoretical and decision making positions in the scientific establishment that determines the research agenda and general curricular focus. Women's health issues and a focus on women are also absent from the curriculum. They assume that since science is "objective", gender does not influence either who becomes a scientist or the science produced by those scientists. Many scientists would suggest that science is "manless" as well as "womanless"; they are unaware or would openly reject the notion that gender might influence the theories, data collection, subjects chosen for experimentation or questions asked.

Phase II. Recognition that Most Scientists are Male and that Science May Reflect a Masculine Perspective.

Recent publicity from the federal government and various professional societies has made most scientists aware that women are under-represented in all natural science fields, particularly in the theoretical and decision-making levels of the profession. Some scientists, influenced by scholarship in women's studies, philosophy and history of science, and psychology have begun to recognize that gender may influence science. Thomas Kuhn[6] and his followers have suggested that all scientific theories are the products of individuals living in a particular historical and social milieu. As such, they are biased by the perspective and paradigms of those individuals. Fee[7] and Keller[8] have suggested that the absence of women from the decision-making levels of science has produced a science that views the world from a male perspective and is, therefore, womanless. The failure of scientists to recognize this bias has perpetuated the idea of the "objectivity" of science.

Phase III. Identification of Barriers that Prevent Women from Entering Science.

Acceptance of the possibility that a preponderance of male scientists may have led to the production of a science that reflects a masculine approach to the world constitutes the first step towards recognition of barriers to women's becoming scientists. An aspect of this phase shows up in the current studies of attempts to attract more women into science and math, the traditionally "male" disciplines. The National Science Foundation,[9] the Rockefeller Foundation,[10] the American Association of Colleges under the auspices of the Carnegie Corporation and the Ford Foundation,[11] the American Chemical

Society,[12] and the Office of Technology Assessment,[13] along with other foundations and professional societies, have each issued studies and reports with statistics documenting the lack of women in science and possible "causes and cures."

Other evidence of the obstacles faced surfaces in article titles written by and about women in science.

- "Adventures of a Woman in Science"[14]
- "Rosalind Franklin and DNA: A Vivid View of What It Is Like to be a Gifted Woman in an Especially Male Profession"[15]
- "Sex Discrimination in the Halls of Science"[16]
- "Women in Academic Chemistry Find Rise to Full Status Difficult"[17]
- "The Anomaly of a Woman in Physics"[18]
- "The Disadvantaged Majority: Science Education for Women"[19]
- "Can the Difference Between Male and Female Science Majors Account for the Low Number of Women at the Doctoral Level in Science?"[20]
- "Obstacles and Constraints on Women in Science"[21]
- "Where Are the Women in the Physical Sciences?"[22]

These titles suggest that women who do become scientists are frequently viewed as anomalies or face numerous problems and difficulties because of their gender.

The dearth of women scientists and the marginalization of the few women who do exist have led to questions about a source of bias and absence of value neutrality in science, particularly biology. By excluding females as experimental subjects, focusing on problems of primary interest to males, faulty experimental designs, and interpretations of data based in language or ideas constricted by patriarchal parameters, experimental results in several areas of biology are biased or flawed. These flaws and biases were permitted to become part of the mainstream of scientific thought and were perpetuated in the scientific literature for decades, because most scientists were men. Since most, if not all, scientists were men, values held by them as males were not distinguished as biasing. Values held by male scientists were congruent with values of all scientists and became synonymous with the "objective" view of the world.[8,23] Fee,[7] Haraway,[24] Hein,[25] and Keller[21] have described the specific ways in which the very objectivity said to be characteristic of scientific knowledge and the whole dichotomy between subject and object are, in fact, male ways of relating to the world, which specifically exclude women.

An additional deterrent for many women is that biological research has been and continues to be used to justify social and political inequalities. Several historical and contemporary[26] examples exist of this usage. If any inequity can be scientifically "proven" to have a biological basis, then the rationale for social pressures to erase that inequity is diminished. In both the nineteenth and twentieth centuries some scientific research has centered on discovering the biological bases for gender differences in abilities to justify women's socially inferior position. Craniometry research and social Darwinism quickly derived from Darwin's theory of natural selection serve as examples of the flawed science used to "prove" the inferiority of women and non-whites.[26] Feminist critics have stated that some of the work in sociobiology[27,28] and brain lateralization[29,30] constitutes the twentieth century equivalents providing the scientific justification for maintaining the social status quo of women and minorities.

Phase IV. Search for Women Scientists and their Unique Contributions.

Although we sometimes labor under the false impression that women have only become scientists in the latter half of the 20th century, early works by Christine de Pizan,[31] Giovanni Boccaccio,[32] and H. J. Mozans[33] recorded past achievements of women in science. Their works underscore the fact that women have always been in science. However, all too frequently the work of women scientists has been credited to others, brushed aside and misunderstood, or classified as non-science. There are several classic examples of the loss of the names of women scientists and the values of their work. Rosalind Franklin's fundamental work on the x-ray crystallography of DNA, which led to the theoretical speculation of the double helical nature of the molecule by Watson and Crick, continues to be brushed aside and undervalued.[34,15] The ground breaking work of Ellen Swallow in water, air and food purity, sanitation, and industrial waste disposal which began the science of ecology was reclassified as home economics primarily because the work was done by a woman.[35] Ellen Swallow is thus honored as the founder of home economics rather than as the founder of ecology.

The recovery of the names and contributions of the lost women of science has been invaluable research provided by historians of science who were spurred on by the work of feminists in history. Much of the work has followed the male model, focusing on the great or successful women in science. Olga Opfell's[36] The Lady Laureates: Women Who Have Won the Nobel Prize and Lynn Osen's[37] Women in Mathematics are based upon this model. Many individual biographies on famous figures such as Marie Curie,[38] Rosalind Franklin,[15] Sophie Germain,[39] Mary Somerville,[40] and Sofia Kovalenskia[41] have also emerged. Demonstrating that women have been successful in traditional science is important in that it documents the fact that despite the extreme barriers and obstacles, women can do excellent science. This work is what Lerner[42] calls compensatory history.

Some historians have rejected this male model and sought to examine the lives and situations of women in science who were not famous. Margaret Rossiter's[43] Women Scientists in America: Struggles and Strategies to 1940 is the ground breaking work that examines how the work of the usual woman scientist suffers from under recognition due to application of double standards and other social barriers inherent in the structure of the scientific community. Londa Schiebinger's work[44] on the role of women in Europe during the period of formulation of modern science documents a lengthy tradition for less famous women scientists.

Recovering the history of women in science often reveals the history of the use of flawed scientific research against women and people of color. Frequently, biologically deterministic theories, such as sociobiology and those regarding hormone effects on the brain, have been used to justify women's position in society. Feminist scientists refute the biologically deterministic theories by pointing out their scientific flaws.[45, 28, 29, 46, 47, 48] Bleier[45] discussed at length the subtle problems that accompany biochemical conversions of hormones within the body, so that an injection of testosterone may be converted to estrogen or another derivative by the time it reaches the brain. She and others have also repeatedly warned against extrapolating from one species to another in biochemical, as well as behavioral, traits. Feminist scientists have warned sociobiologists about the circularity of logic involved in using human language and frameworks to interpret animal behavior, which is then used to "prove" that certain human behavior is biologically determined, since it was also found in animals.

Phase V. Science done by feminists/women.

Uncovering women scientists and their contributions provides an opportunity to examine differences between their work and that of men scientists. Similarly, awareness of possible biases and flaws introduced into research from the dominance of males and a masculine perspective in science led to explorations of unique aspects of science done by women. Three examples of recent work suggest possible differences between males and females in distance between scientist and subject of study, use of experimental subjects, and language.

1. Barbara McClintock was an achieving scientist who is not a feminist. However, in her approach towards studying maize, she indicated a shortening of the distance between the

observer and the object being studied and a consideration of the complex interaction between the organism and its environment. Her statement upon receiving the Nobel Prize was that "it might seem unfair to reward a person for having so much pleasure over the years, asking the maize plant to solve specific problems and then watching its responses."[50] This statement suggests a closer, more intimate relationship with the subject of her research than typically is expressed by the male "objective" scientist. One does not normally associate words such as "a feeling for the organism"[50] with the rational, masculine approach to science. McClintock also did not accept the predominant hierarchical theory of genetic DNA as the "Master Molecule" that controls gene action but focused on the interaction between the organism and its environment as the locus of control.

2. Models that more accurately simulate functioning, complex biological systems may be derived from using female rats as subjects in experiments. Women scientists such as Hoffman[51] have questioned the tradition of using male rats or primates as subjects. With the exception of insulin and the hormones of the female reproductive cycle, traditional endocrinological theory predicted that most hormones are kept constant in level in both males and females. Thus, the male of the species, whether rodent or primate, was chosen as the experimental subject because of his non-cyclicity. However, new techniques of measuring blood hormone levels have demonstrated episodic, rather than steady, patterns of secretion of hormones in both males and females. As Hoffman[51] points out, the rhythmic cycle of hormone secretion, as also portrayed in the cycling female rat, appears to be a more accurate model for the secretion of most hormones.

3. As more women have entered primate research, they have begun to challenge the language used to describe primate behavior and the patriarchal assumptions inherent in searches for dominance hierarchies in primates. Lancaster[52] describes a single-male troop of animals as follows:

> For a female, males are a resource in her environment which she may use to further the survival of herself and her offspring. If environmental conditions are such that the male role can be minimal, a one-male group is likely. Only one male is necessary for a group of females if his only role is to impregnate them.

Her work points out the androcentric bias of primate behavior theories, which would describe the above group as a "harem" and consider dominance and subordination in the description of behavior. Discribing the same situation using a gynocentric term such as stud reveals the importance of using more gender-neutral language such as that suggested by

Lancaster to remove bias.

Phase VI. Science Redefined and Reconstructed to Include Us All.

The ultimate goal of the curricular changes suggested in phases I-V is the production of curriculum information which includes women and therefore attracts individuals from diverse groups to become scientists. Obviously, this curriculum has not been fully developed yet. Achievement of phase VI should accomplish more than increasing the diversity of individuals who choose to become scientists. Phase VI should also result in a better science which suffers from fewer flaws and biases. As more people from varying backgrounds and perspectives become scientists, they increase the likelihood that the scientific method will be able to function as it should. As long as most scientists come from a relatively homogeneous perspective - that of the white, middle/upper class Western male - their view of the world and science will be limited by that perspective. When scientific hypotheses are held up for critique to the scientific community, biases and flaws in the hypotheses are likely to go unseen to the extent that the scientific community holds a relatively homogeneous perspective. This homogeneity in gender, race and class is what caused the scientific community to fail to include women and men of color in definition of problems for study, as experimental subjects in drug tests, and in applications of research findings.

Expansion of the pool of scientists to include individuals from both genders and diverse races and classes will eliminate the homogeneity that resulted in this flawed science while strengthening the rigor of the scientific method. The broadened scope of problems explored, expanded approaches, and less biased theories produced by this more diverse group of scientists will be reflected in the scientific curriculum. This transformed curriculum should in turn attract a larger more heterogeneous group to become scientists.

Pedagogical Changes to Accompany Transformed Curricular Content:

Transformation of curriculum in the sciences to include women and people of color may provide a model for improving science through increased diversity. The six phase model presented demonstrates the steps which might be taken to transform a science curriculum in which the absence of women is not noted (phase I) to an inclusive curriculum (phase VI). As faculty move through the various phases of curriculum transformation from recognition that most scientists are male (phase II) and examination of barriers that have prevented women from becoming scientists (phase III) to a search for women scientists (phase IV) and a focus on work done by women/feminist scientists (phase V), they begin to transform their teaching techniques in the light of their new knowledge. Although some techniques maybe more appropriate for one particular stage, many of the following twenty pedagogical techniques may be appropriate to accompany multiple stages of the curriculum.

1) Expand the kinds of observations beyond those traditionally carried out in scientific research. Women students may see new data that could make a valuable contribution to scientific experiments.

2) Increase the numbers of observations and remain longer in the observational stage of the scientific method. This would provide more hands-on experience with various types of equipment in the laboratory.

3) Incorporate and validate personal experiences women are likely to have had as part of the class discussion or the laboratory exercise.

4) Undertake fewer experiments likely to have applications of direct benefit to the military and propose more experiments to explore problems of social concern.

5) Consider problems that have not be considered worthy of scientific investigation because of the field with which the problem has been traditionally associated.

6) Formulate hypotheses focusing on gender as a crucial part of the question asked.

7) Undertake the investigation of problems of more holistic, global scope than the more reduced and limited scale problems traditionally considered.

8) Use a combination of qualitative and quantitative methods in data gathering.

9) Use methods from a variety of fields or interdisciplinary approaches to problem solving.

10) Include females as experimental subjects in experimental designs.

11) Use more interactive methods, thereby shortening the distance between observer and the object being studied.

12) Decrease laboratory exercises in introductory courses in which students must kill animals or render treatment that may be perceived as particularly harsh.

13) Use precise, gender neutral language in describing data and presenting theories.

14) Be open to critiques of conclusions and theories drawn from observations differing from those drawn by the traditional male scientist from the same observations.

15) Encourage uncovering of other biases such as those of race, class, sexual preference, and religious affiliation which may permeate theories and conclusions drawn from experimental observation.

16) Encourage development of theories and hypotheses that are relational, interdependent, and multicausal rather than hierarchical, reductionistic, and dualistic.

17) Use less competitive models to practice science.

18) Discuss the role of scientist as only one facet which must be smoothly integrated with other aspects of students' lives.

19) Put increased effort into strategies such as teaching and communicating with nonscientists to break down barriers between science and the lay person.

20) Discuss the practical uses to which scientific discoveries are put to help students see science in its social context.[53]

This changed pedagogy should attract more students from more diverse backgrounds to become scientists, increasing the perspectives of the scientific community and strengthening the rigor of the scientific method. Curricular change combined with transformed pedagogy will result in more scientists from diverse backgrounds to confront the increasingly complex problems of our scientific, technological society.

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