the NIH budget will not keep up with inflation. Of the grant applications selected as scientifically promising, fewer than one in four were funded last year (*19*). But, if basic research is so cost-effective, one may ask, why isn't it fully supported by the insurance or pharmaceutical or biotechnology industries? Because scientific inquiry can take years and lead in unexpected directions, the potential financial returns on any single scientific investigation may not justify the investment in the short run. Like the construction of interstate highways, biomedical innovation pays for itself times over in the aggregate, but it is too big an endeavor for any private investor. The provision of this kind of public good is an appropriate role of the government.

Although biomedical innovation was ignored in the Clinton health plan in Congress, there has been strong bipartisan support for increased investment in biomedical research as part of health care reform. Many members of Congress are recognizing the importance of training scientists and physicians, maintaining research hospitals and facilities, and continuing the flow of new discoveries. Despite the current dwindling of discretionary spending, several senators and representatives have proposed a Medical Trust Fund which would provide 1% of health care insurance premiums for biomedical research. The fund is based on the principle that just as industry invests in research with a profit motive, some part of health care reform should invest in biomedical research with a goal of cost saving and quality improvement.

After the inevitable political compromises to enact health care reform, it is critical that the resulting policy includes appropriate incentives for cost-reducing innovation and adequate public funding for NIH to support basic biomedical research. Federal support for biomedical research, which has focused on the benefits to health, should incorporate a realistic accounting of the contribution of innovative research to cost control as well. Past biomedical innovation has made major contributions in advancing medicine and significant contributions to cost reductions in spite of skewed incentives. With corrected incentives, the promise of future biomedical innovation to reduce costs is enormous. Only innovation will enable the dramatic and sustained cost reductions required for successful health care reform.

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The Paradox of Critical Mass for Women in Science

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A minority group (especially one that has traditionally been discriminated against) is easily marginalized when only a small presence in a larger population; its continued presence and survival is in constant jeopardy, requiring outside intervention and assistance to prevent extinction. As the group's presence and level of participation grows, at a particular point the perspective of members of the minority group and the character of relations between minority and majority changes qualitatively. In theory, the minority is increasingly able to organize itself and insure its survival from within and effects a transition to an accepted presence, without external assistance, in a self-sustaining process (*1*). The discrete point at which the presence of a sufficient number brings about qualitative improvement in conditions and accelerates the dynamics of change is known as "critical mass" and has been defined as a strong minority of at least 15% (*2*). Change, without struggle, however, is less likely than conflict with determined resistance. Under certain conditions, an organizational transformation culminates in minority group members achieving and retaining positions of real power and authority that were previously beyond their grasp (*3*).

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To evaluate the dynamics and effects of these transitions for the problem of increasing participation of women in science, we studied 30 academic science departments in five disciplines (biology, chemistry, physics, computer science, and electrical engineering), comparing those departments that had been relatively successful in graduating female Ph.D.'s to those that had not (*4*). We also compared departments where a critical mass of women existed to departments where it was lacking.

A key finding was that as the number of women faculty members in a department increased, they divided into distinct subgroups that could be at odds with each other. Senior female scientists typically shared the values and work styles of older men; their narrow focus failed to meet the needs of most younger women. In contrast, some younger women (and a few men) struggled to create an alternative scientific role, balancing work and nonwork issues.

The scientific role thus bifurcates along generational and gender fault lines. These developments have significant unintended consequences for the socialization of female scientists, for example, the availability of relevant role models. As long as the relatively few women in academic science were willing to accept the strictures of a workplace organized on the assumption of a social and emotional support structure provided to the male scientist by an unpaid full-time housewife or done without, issues of women in science were not attended to. A modest increase in the numbers of women in science, without a change in the structure of the scientific workplace, creates a paradox of critical mass.

Attaining Critical Mass

Alice Rossi's question of almost 30 years ago: "Why so few women in science?" must be revised to reflect changing patterns of participation (5). The proportion of women among doctoral scientists and engineers doubled between 1975 and 1991. But while all fields showed gains, the starting points and rates of change have varied widely from discipline to discipline (6).

Women-friendly subfields have emerged in the life sciences and in biologically oriented subfields in chemistry, biochemistry; in computer science, artificial intelligence where cognitive processes and psychological links are prevalent; and in the bioelectrical subfield of electrical engineering. These fields tend to be ones that women select or are subtly or not so subtly directed into. In a snowball effect, as numbers increased, more women were attracted.

We found that modest increases in the number of women did bring about some change in departments. In this respect, critical mass does work smoothly: There is more support and safety in numbers. A female student observed that, "One good thing is that there were female faculty members. It definitely changes the attitude of how male students react to women. They must take them seriously and this is positive." When senior females were present, overt male behavior toward women improved (for example, invidious public sexual joking and stereotyping declined); this change is a threshold effect of critical mass.

Involvement of respected senior faculty members also was the key to some instances of actual departmental reform. A "revolution from above" opened up a tenure slot for a woman when members of a male leadership group in one department became aware of, and decided to eliminate, implicitly discriminatory practices. A cultural change was initiated as well, making the department amenable to the presence of women. Sympathetic men as well as women served as change agents.

For these reasons in departments with no women faculty, female graduate students often had high expectations about the presence of a female faculty member. A female graduate student said:

> I wish we had a woman because the men don't understand the issues that the women are concerned about. I thought about going to the chair and telling him to put all the new graduate students in the same area of the building because it's really helped us get through the first year. But he may say, "why?" Maybe that's not important to the men. But if there was a woman who was higher up then I could say this is really cool to have some companions, some support system here, and she might say, "Yeah, that's really a nice thought."

Another female graduate student expressed the need to learn how to comport herself as a woman in professional situations:

> If I had the choice of a female [adviser], I would choose one. She would be a role model in regard to how to dress, how to act at conferences, what to do when someone is curt to you. I am more than willing to admit that there are differences in the genders. I would like to have someone who can show that I can do it. I am looking for sensitivity about the issues that I perceive that I deal with. Men and women have different issues.

However, particularly in the absence of a critical mass, expectations about the ability of individual female faculty, especially those who are untenured, to bring about change in departmental conditions are unlikely to be realized. A junior female faculty member recounted the perils:

> My gut level feeling was that the attrition for females was higher. I just went in, seat of the pants, and looked over the past 10 years. You could see by the number of women admitted, and then in a 6-year-frame shift of how long it takes to graduate, that there was a big difference between male and female attrition. With our male colleagues you need hard data, or else they won't accept it. So I took a particular year and followed the students, and within the first 2 years 50% of the females had left. The males were 17%. I mentioned this to one of my male colleagues, who told me I had lost my mind. He just said it wasn't possible for this factor to be true. They don't realize. They have no concept. Once confronted with actual numbers and people, they say, "well, we ought to know about this. Nobody's ever told us." First there's general disbelief. Then you show them the data and they look at it and they're honestly shocked. They personally don't recognize it in their everyday lives. One [colleague] told me I was lying. They said "why don't you give a presentation to the faculty at a faculty meeting and discuss this fact. Show us the hard data." I'm not sure that I want to put myself on the hot seat like that. Get up in front of the whole faculty? As strongly as I feel about this, I don't want to subject myself to what might possibly happen by standing up in front of a group of those people and telling them what is going on in the department.

As an isolated individual, there was little she could do given expectations of an invidious response.

Even worse, in some cases, stigmatization of women accompanied the breakdown of gender uniformity. Seemingly innocuous measures like calling together an informal group of women were sometimes perceived negatively and forestalled. Untenured women, concerned that participating in activities for women would set them apart, were sometimes unwilling to participate.

The Paradox of Critical Mass

We found that attainment of critical mass only partly resolved the dilemma of women in academic departments. The fallacy of critical mass as a unilateral change strategy is that female faculty pursue strikingly different strategies. Despite some progress, organizational structures within departments, and the divisions they engendered, continued to isolate women. Furthermore, the dispersal of women students into male-dominated research groups sustained isolation even when there was a critical mass in a department. Nor did an improvement in the total number of women in a department necessarily overcome an underlying situation of subfield fragmentation that further increased the isolation of women.

Isolation is widely recognized as a problem for women in academic science, carrying with it a variety of negative consequences including stigma, depletion of self-confidence, and exclusion from access to informal sources of professional information. Informal networks are indispensable to professional development, career advancement, and the scientific process. Contiguity of helpful colleagues improves the conditions for scientific achievement; lack of sympathetic interaction depresses it. Isolated individuals not only lack social psychological support, but also the social capital underlying success (7). As outsiders, some female scientists developed strategies to make up for these deficits.

The differentiation of female faculty produces isolation even when the numbers reach critical mass. Even when there are several female faculty members present, female graduate student expectations for change may be thwarted. In this department, "you are either a superstar or you're marginal. I came here to find a critical mass of women faculty who would be cohesive. But they're not. They are isolated from each other."

Even when isolation should be reduced by the presence of several women faculty members in a department, their dissensus was apparent. Indeed, female graduate students in our sample expressed surprise and discouragement at encountering this unexpected phenomenon. This is especially the case for entering female graduate students with little or no awareness of the appropriation of the male model of doing science by women faculty or of the pressures on them. Such false assumptions on the part of female graduate students often lead to disappointment, frustration, and even anger or despair.

"Male" and "Female" Models

One reason for continued isolation and the paradox of critical mass was that female scientists split into subgroups following one of two paths, "the traditional male" and "the relational female" models. Thus, as it was achieved, some of the expected effect of critical mass dissipated. A modest increase in the number of women has brought about a breakdown of a unitary male model, but the growing number of women students often lack viable role models in the interim, as normative change takes hold. Some female scientists singularly focused on science, and their identity was narrowly based on research and career achievement. Marriage and children were secondary for these women; most waited until after achieving tenure to marry and start a family, if they chose to do so at all. A senior female scientist described her cohort:

The ones who did [science] were really tough cookies. Now it's easier to get in. At one time it wasn't even acceptable to start. So if you started back then you were tough to begin with. I have quivering women coming through who are very smart asking can they compete with men, and can they compete on a very competitive, fierce playing field. Of course they can. They just are not taught to be competitive. They don't expect to win. The reason why I am successful is because I never felt this way.

Their experience in overcoming discrimination led these scientists to expect that women had to be better than men in order to succeed; they trained their female students accordingly. A female graduate student described her adviser: "The generation of women scientists that [my adviser] belongs to, some of them feel they have to go that extra professional push to be taken seriously or to gain the same respect from their peers that men do. [My adviser] said you have to be careful how you present yourself. You have to be more rigorous." They felt they had to be tougher on women students than men, to prepare them to meet the higher standards they would be held to as women.

Female scientists following the male model believed they were helping their female advisees by toughening them up to survive in a harsh environment. A female graduate student reported that:

I happened to pick a woman adviser ... which turned out to be somewhat of a mistake. I was under the impression that having a woman adviser would make life a little bit easier. ... It turned out to be worse. ... Their motto is sink or swim. ... My adviser's approach was to put it too far out of my grasp."

This response from a woman was experienced as debilitating and depressing and was taken more negatively than if it had come from a man.

Fear of stigmatization led some women who have made it to deny the existence of gender-related obstacles. Calling attention to difficulties overcome could lead to countercharges of special privileges received, devaluing their achievements. Frustrated by the emergence of women's issues, they regarded such concerns as indicative of lack of commitment to science. They believed women's groups and programs to improve the condition of women harmed female scientists by making them appear "different," and by implication less competent. Most women following the male model are from a courageous older generation; it is premature to conclude that academic science has opened up sufficiently to make their stringent approach, which was highly adaptive in the past, irrelevant today.

Only a relatively few women are willing to follow the male model and even some men would like to modify it. Some males, both students and faculty, are struggling with some of the same issues of balancing career and family as women. Some junior male faculty were more sympathetic mentors than some senior female faculty. It is not only the number of women faculty members that aids female students; a conduit of information about negotiating the social structure of science, both its hidden and visible rules, is crucial. This information can come from women or men.

Thus, some women scientists whom we interviewed have formulated an alternative scientific role and work style based on creating a collegial and supportive environment in their research groups (8). Viewing science as only one part of their identity, they strived to balance the demands of career and family. Integrating science and personal life was the paramount issue for women students. A female chemist said, "The biggest problem women students have has to do with the whole culture: How do you do [science] and have a normal life? It's a constant problem. They ask me when they should have children, can I take a part-time postdoc and then get back in? I don't know [the answers]. I can't help them."

These female scientists struggled to find the best time to schedule their pregnancies, given a rigid academic career structure demanding early achievement (9). They viewed themselves and their husbands as the mutual primary caregivers of their children and were unwilling to turn this responsibility over to others. Nevertheless, they were interested in high-quality child care as a secondary support system and often felt frustrated at the low priority this need was given at most universities. A female faculty member said:

I have seen female graduate students come to this department who are exceptional, who did not leave because of academics whatsoever. Outshined many of the men by orders of magnitude, and they're gone. And I consider that such a waste. I look at these people as being excellent people who could go on and be in academia, and they leave with a master's because they say they don't want to live like this. They see what people have to do to succeed in academia. They look at a junior male faculty member and what they have to do, and they extrapolate what they would have to do for themselves. The women want to have another life; they want a family, [to] be able to socialize on the weekend. It doesn't have to be like that, but that's what they see; working on the weekends and every night.

Women scientists' unmet needs have posed several other problems as well. The limited acceptance of a female relational model and a mentor's career setback were discussed by a female graduate student:

I was so upset when I found out that she didn't get tenure at this time because she's been such an asset to me and so many other women that I know ... as a mentor. As someone I could look at and say I could be there someday. Someone who actually proves the reality that there can be a professor [here] who is normal, that you can relate to. She is a role model. I'm not sure what I want to do right now, but I wanted to have the opportunity of going into academics open. She seemed like an open road in that direction. When the door was closed on her, I felt the door was closed on me too.

Without such role models, women are less willing to attempt careers in academic science. Invidious definitions of female affiliation highlight the structural nature of the problem and the need to address isolation at the highest levels of academic and science policy (10).

Policy Implications

Critical mass was expected to be achieved through affirmative action, to clear up blockages in the pipeline on the premise that a sufficient number of persons from a previously excluded social category will foster inclusion of others from that background. From the 1970s, efforts to increase the number of women in academic science departments have largely resided in affirmative action programs, requiring full consideration of female and minority candidates. However, in the 1980s lack of vigorous enforcement reduced the spirit of the law into a bureaucratic requirement that became a routine part of the paperwork of the academic hiring process, often with little or no effect on recruitment and no impact upon retention (11). Nor did this strategy, focused on getting entrants into the system, address the hidden inequities of academic departments.

The paradox of critical mass and the interest of many female scientists in creating an alternative relational mode of doing science suggests that a significant increase in the number of women in academic science is unlikely to occur simply by increasing the numbers of women who embark on a scientific career. Encouraging more women to enter the pipeline is fruitless if so few emerge as professional scientists. At each transition point the number of women decreases at a significantly higher rate than for men: For women the pipeline is an exceedingly leaky vessel. In the face of exclusionary practices, both explicit and implicit, built into the research university system, many women Ph.D.'s, seeing the handwriting on the wall and seeking to balance work and personal life, sought employment in industry and teaching colleges. As our observations emphasize, the pipeline, a supply-side approach, needs to be supplemented by a focus on changing the institutional structures where science takes place.

A key factor in overcoming the problems posed by the paradox must be universitywide policies and programs regarding child care, parental leave, recruitment and retention, and slowing of the tenure clock (*12*). At the departmental level, junior faculty who assume mentoring and role modeling functions should be credited in tenure reviews. Tokenism must be eschewed: Many departments aggressively court a few female stars while most women languish in continued discrimination.

Some reforms must come from internal initiatives, overcoming divisions arising from the emergence of subgroups following male and female models. Female scientists in academia and industry have undertaken innovative efforts to reduce isolation and provide information and support to graduate students. Electronic mail lists, such as SYSTERS for women in computer science and an electronic mentoring project, drew geographically isolated individuals together into an informal network (*13*). Some departmental secretaries took upon themselves, or were assigned, the task of organizing support groups. University counseling staff also provided a resource for female students. Another change strategy, organizing retreats and support groups, was sponsored by some departments and National Science Foundation (NSF) Engineering or Science Centers.

Nevertheless, the ability of departments to defend traditional academic practices as gender neutral should not be underestimated, nor should willingness to reform themselves be overestimated. Unable to reform themselves, outside pressures provide the necessary incentive for most departments. A representative of WISE (Women in Science and Engineering at Columbia University) recently suggested that the NSF cut off grants to universities without a minimum number of female faculty in science and engineering departments. Indeed, NSF has mandated that absence of women at conferences that it funds will be taken as prima facie evidence of discrimination. Single-sex graduate departments have also been proposed to address the persisting exclusion of females from male inner circles (*14*).

Legal action is a final resort. Until quite recently, courts were generally unwilling to review academic decisions on substantive grounds; only matters of procedure were typically subject to judicial review. Gender discrimination has now been accepted as a valid basis for law suits challenging academic decisions, following widespread acceptance of its legitimacy in other workplaces. Jenny Harrison, a University of California, Berkeley, mathematician, was recently granted tenure after such a suit. The recognition she received for a series of significant results made the initial negative decision a matter of some embarrassment to the mathematical community. Academic exceptionalism, whether in the courts or Congress, is disappearing as universities are held to ethical, legal, and financial standards common to all public institutions.

Participation of all groups in society is a basis for the public support of science. The legitimation of science, the moral injunction to achieve equity, and the strategic national interest in utilizing talent to its fullest extent are reasons for change. Neal Lane, the director of NSF, has called upon the research community to act in its own self-interest and make a conscious effort "to integrate itself into the larger community" by more closely reflecting the demographic composition of the population (*15*). Equal representation of women and men in scientific professions would counter the elitist image of science and hopefully earn increased support for allocation of public resources to science.

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