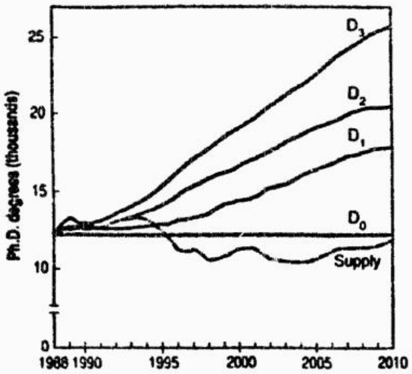

Fig. 7. Supply and demand projected to the year 2010 for Ph.D.'s in the natural sciences and engineering. Four different demand scenarios are indicated by the D_0, D_1, D_2, and D_3 curves.

the remainder in federal, state, and local governments. Slightly more than 40% of these new Ph.D.'s were replacements hired to fill existing positions created by deaths and retirements; the remainder filled new positions created as a result of expanding programs in academia, industry, and government (Table 1).

If the projected demand for new Ph.D.'s in science and engineering were to remain constant at the 1988 level, there would be more than enough new Ph.D.'s until about 1995. Thereafter, a slowly increasing shortfall between demand and supply would develop that would reach a maximum of about 1500 in the year 2003 and would virtually disappear by 2010. This demand scenario is labeled D_0 in Fig. 7.

But the constant D_0 scenario is highly unlikely for at least three reasons. First, yearly replacements due to retirements and deaths are expected to increase over the next two decades. Second, college and university enrollments are almost certain to increase in the late 1990s with the expanding college-age population, necessitating an increase in the number of faculty hired. Third, if federal and private investments in R&D continue to grow at even moderate rates, the number of new Ph.D.'s required by industry will be well above the 1988 level. These three factors generate three additional demand scenarios labeled D_1, D_2, and D_3.

Let us consider first the number of new Ph.D.'s required to fill existing positions as they are vacated because of retirements and deaths. That replacement demand was 5080 in 1988 for the academic, industrial, and government sectors combined (Table 1). Because of the age distribution of the Ph.D. work force, the replacement demand is anticipated to increase steadily over the next two decades and reach about 11,000 in the year 2010. This effect will be particularly evident in academia: most of the faculty hired during the boom period of the 1960s are still in place, but they will begin to retire in large numbers starting in the late 1990s (*7*).

The expected number of replacements is well documented, and there is little disagreement among experts about these numbers. Adding an increasing number of replacements to the D_0 scenario yields the D_1 curve (Fig. 7). This projection suggests that the shortage of Ph.D.'s will become evident in about 6 years.

In the short term, pressures created by an increasing demand for new Ph.D.'s in the nonacademic sectors are likely to be offset somewhat by a decline in the number of new faculty required to teach a decreasing number of college students. The analysis by Bowen and Sosa (*7*) indicates that all academic fields (sciences, humanities, and the arts) are likely to experience an excess supply of new Ph.D.'s until the mid-1990s, after which time the situation will rapidly reverse itself with demand outstripping supply well into the next century. That rapid reversal will occur because large numbers of faculty will be retiring just as college enrollments begin to increase once again (*10*).

Table 1. Categorized breakdown of the demand for Ph.D.'s in 1988 (*9*).

Organization	Replacement positions	New positions
Universities and colleges	2896	2667
Industry and business	1422	3646
Government	762	796
Total	5080	7109

As colleges and universities scramble to fill positions created by faculty retirements, they will be faced suddenly with rapidly increasing enrollments linked to the demographics of the college-age population. Assuming that the current student/faculty ratio is maintained in future years, there will be an additional demand for new Ph.D.'s to fill the expanding faculties. In 1988, the number of new positions created in colleges and universities was 2667 (Table 1); that number will fluctuate for the next several years and then grow steadily to about 5250 by the year 2010. If this increased demand is added to the D_1 scenario, the result is the D_2 curve (Fig. 7). This curve might be damped somewhat by increasing the current student/faculty ratio or by adopting policies that reduce the percentage of high school graduates going on to college, but those changes would bring a corresponding reduction in both the quality and availability of higher education.

The D_0 scenario is based on the assumption that the nonacademic sector (business, industry, and government) will add 4442 new Ph.D.-level positions to the labor force on an annual basis—in addition to replacements (Table 1). The NSF study (*9*) indicates that this growth forecast is too conservative, given historic correlations between R&D investment and the need for new Ph.D.'s. It argues that the base number should grow at an annual rate of 4% in order to maintain economic growth and international competitiveness. Given a 4% growth rate, the 1988 level of 4442 new Ph.D.-level positions would increase to about 9600 by the year 2010. Adding these positions to the D_2 demand curve generates the curve labeled D_3 (Fig. 7).

These four demand scenarios are summarized in Fig. 8. Supply and demand estimates averaged over the 16-year period from 1995 to 2010 are presented, along with the average annual shortfall. Shortfalls range from 950 for the D_0 case to 9600 for the D_3 case. Such annual shortfalls yield cumulative shortfalls over the 16-year period that range from 15,200 for D_0 to 153,600 for D_3.

My own judgment is that the D_3 projection should be given the most serious consideration (*11*). It does not represent an extreme case; it requires simply that the current student/faculty ratio be maintained in future years and that there be about an annual 4% growth rate for the number of new Ph.D.'s hired by business, industry, and government. These are minimal requirements if we believe that education and research are critical for economic growth,

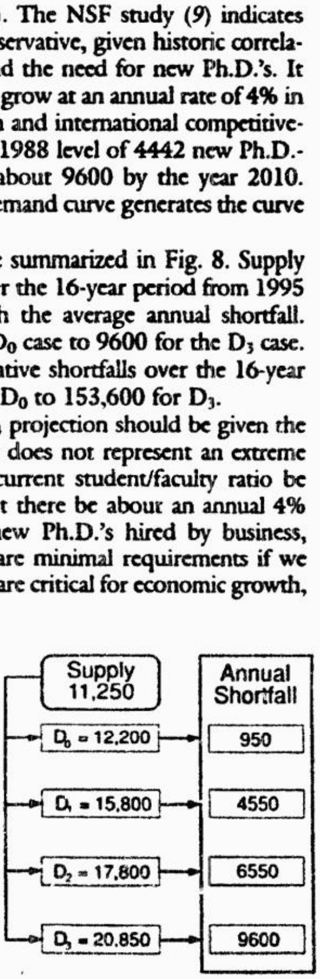

Fig. 8. The annual supply and demand for new Ph.D.'s in the natural sciences and engineering averaged over the 16-year period from 1995 to 2010.

international competitiveness, advances in health care, and national security. The D_0 case is completely unrealistic, unless we are prepared for a dramatic deterioration in the nation's education and research enterprises.

Market mechanisms will no doubt reduce projected shortfalls between supply and demand, but they will be slow in coming and expensive. As competition for a dwindling supply of new Ph.D.'s intensifies, the percentage of baccalaureate recipients who pursue Ph.D.'s in anticipation of improved employment opportunities is almost certain to increase. But that positive market signal will not be transmitted for several years. Until then, a declining demand for faculty is likely to transmit a negative signal to new baccalaureates about the rewards of graduate study. In any event, market mechanisms alone are not likely to yield appreciable additional Ph.D.'s before well into the next century. Prudence suggests, therefore, that we pursue intervention strategies to increase the future supply of Ph.D.'s by increasing the number of college students who complete baccalaureate degrees in science and engineering, and increasing the number of baccalaureate recipients who go on to obtain Ph.D.'s.

Recruitment and Retention Strategies

Are there enough qualified students to increase the production of scientists and engineers without compromising quality? Statistics collected by the Department of Education suggest that there are. These data are based on surveys that track students in the high-school classes of 1972, 1980, and 1982 beginning with their freshmen year in college (*9*). The results indicate that a large fraction of interested and qualified students are "lost" to science and engineering between their freshman and senior years in college. For the high school class of 1980:

- Only 46% of those freshmen who declared their intention to major in science or engineering eventually received baccalaureate degrees in those fields.
- Of the freshmen who switched out of science and engineering, only 31% did so because they found the course work too difficult; 43% found other fields more interesting; and 26% believed they would have better job prospects elsewhere.
- The loss of declared science and engineering students between the freshman and senior year is greater for women than for men and is greatest for underrepresented minorities.

Information about qualified students (B+ or better) who are lost to science and engineering before the freshman year in college may be even more significant for devising effective retention strategies:

- Only 58% of qualified high school seniors enrolled in 4-year colleges; 21% enrolled in 2-year or vocational colleges; and 21% did not enroll in any college at all.
- Of the 21% who did not enroll in any type of college program, fully one-fourth had taken ten or more semesters of mathematics and science in high school.

The latter group of students (with both high grades and ten semesters of science who failed to enroll in college) was about 25% of the size of the group of all students entering college with declared majors in science and engineering. The projected shortfall of the next two decades could be largely avoided if such students went on to college in science and engineering, even allowing for subsequent attrition.

These data suggest that several strategies could increase the number of baccalaureate degrees in science and engineering. Some of these strategies would be relatively straightforward. For example, targeted financial assistance could increase the likelihood that qualified high school students would enroll in 4-year colleges. Likewise, effective counseling in addition to financial assistance could help ensure that greater numbers of qualified students in 2-year colleges would have an opportunity to pursue science and engineering majors in 4-year colleges.

Retention strategies should be aimed at reducing the number of students who drop out of college, or who change from science and engineering majors to other fields. With respect to the latter, the sciences have the highest defection rates of any undergraduate major and also the lowest rates of recruitment from other fields (*12*). Anecdotes abound about science faculty who take pride in the number of students who drop their courses; they apparently equate student dropouts with rigorous instruction. Such attitudes toward teaching need to be reassessed; they are especially troubling given that the sciences attract a disproportionate number of academically superior college freshmen.

Fellowships for Graduate Education

Strategies for retaining greater numbers of students in science and engineering through high school and college need to be explored. However, even if effective programs could be put in place immediately, such programs would not generate substantial increases in science and engineering Ph.D.'s for at least a decade. Consequently, we need to ask whether more of the current baccalaureate recipients can be recruited to graduate work.

Statistics on the high school class of 1972 suggest that 20% of the men receiving baccalaureate degrees in science and engineering and 9.4% of the women eventually went on to earn some type of advanced degree. But the number actually earning Ph.D.'s in science and engineering was only 5.5% for men and 3% for women (*9*). Many of the science and engineering baccalaureates who pursued advanced degrees in other disciplines or in professional schools decided that there were inadequate opportunities in science and engineering. Among baccalaureate recipients entering the labor market directly from college, many seem to have decided that the time and financial sacrifice required for a Ph.D. were not worth the anticipated returns.

Better information about the impending shortage of scientists and engineers might convince more baccalaureate recipients to pursue the Ph.D. This information coupled with substantial increases in financial support for graduate work could be even more effective. During the period from 1969 to 1989 the number of federally funded graduate fellowships and traineeships decreased from about 60,000 to less than 14,000. Although research assistantships increased from 20,000 to about 35,000 in the same period, this gain did not approximate the decline in fellowships and traineeships (Fig. 9).

The exact mix of fellowships, traineeships, and research assistant-

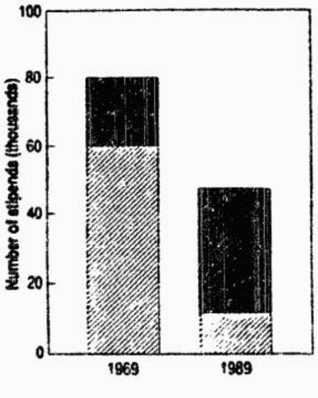

Fig. 9. Federally supported student stipends at the doctoral level. The solid section of the bar shows research assistantships, and the diagonal line section shows fellowships and traineeships. [Source: National Science Foundation]

ships that should be proposed to deal with the impending shortage of Ph.D.'s needs careful study. Any such proposal for federal support should have the following features: (i) be sufficiently flexible so that it can be modulated as updated information becomes available about supply and demand; (ii) have a mechanism to ensure that awards are targeted toward fields with the most serious shortfalls; and (iii) have special incentives for underrepresented minorities and women. A group such as the National Science Board should examine various funding options and mixes of fellowships, traineeships, and research assistantships and then make proposals.

Fellowship programs (which award support directly to students) and traineeship programs (which award funds to university departments, who then select the students to be supported) can allocate resources competitively on the basis of equally rigorous judgments of quality; the difference is whether students or departments are the unit of competition. One advantage of traineeship programs is that judgments in such competitions generally result in broader geographic distributions than do the choices of students in portable fellowship programs; such an outcome can make traineeships more attractive to Congress.

A comprehensive program for the production of more Ph.D.'s should be initiated immediately. Even with the scientific community united behind the need for such a program, it would probably take several years to formulate a broad-based plan, to convince Congress of the need, and to secure the required funding. In the meantime, a first step should be taken now—in anticipation of a more comprehensive program. What I have in mind is immediately establishing a National Program for Graduate Study similar to the National Defense Education Act (NDEA) program created after Sputnik. (Although it was called the NDEA Title IV Fellowship Program, it was in fact a traineeship program.) I described such a program to the Regents of the University of California (*13*). It called for 4-year traineeships funded at the level of \$25,000 per year (a \$16,000 stipend and tuition waiver to the student, plus \$9,000 to the university in lieu of tuition and fees). To begin to deal with the Ph.D. shortfall, at least 3,000 new traineeships per year would be needed. At steady state there would be 12,000 traineeships in any given year at an annual cost of \$300 million.

This effort alone would be insufficient for coping with the impending shortage of Ph.D.'s and would need to be supplemented with additional fellowships and research assistantships (*14*). However, as was the case with the NDEA program after Sputnik, this program would draw national attention to the fact that a serious problem exists. With a concerted effort, it could be sold to key members of the Administration and Congress during the coming months and be part of the budget package sent to Congress in January 1991.

Women and Minorities in Science and Engineering

To be effective, strategies aimed at increasing conferral rates at the baccalaureate and doctoral levels should place special emphasis on population groups for which significant increases can be anticipated. Women are the most obvious of these groups. There has been a slow but steady increase in science and engineering baccalaureate conferral rates for women over the past 30 years, from less than 1% of 22-year-old females in 1959 to 2.5% in 1986. The increase has offset a slow, parallel decline in the conferral rate for males.

In recent years, however, efforts to advance participation of women in science have stalled. The number of science and engineering doctorates awarded to women increased from the late 1950s into the early 1980s but has not increased substantially for the past several years (Fig. 10). An Office of Technology Assessment report concluded that the principal reason for the slowdown in women's interest in science and engineering careers is that women continue to experience higher unemployment, lower pay, and fewer promotion opportunities than their male counterparts (*15*). Special efforts must be made to retain women at the baccalaureate and doctoral levels and to ensure that their talents and training are more fully rewarded (*16*).

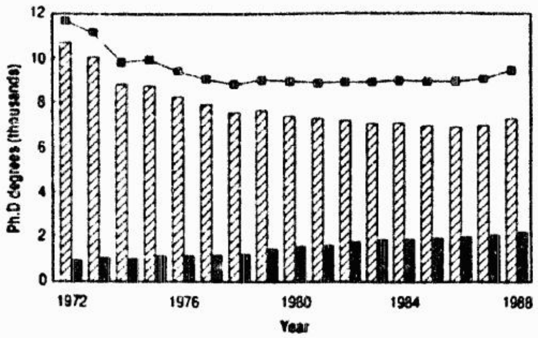

Fig. 10. Number of Ph.D. degrees awarded to U.S. citizens in the natural sciences and engineering from 1972 to 1988. Diagonal line bar represents men; solid bar, women; and squares, the total. [Source: National Science Foundation]

Underrepresented minorities, particularly blacks and Hispanics, present a more difficult challenge. Currently, these two groups make up 20% of the college-age population; they will make up 25% by 1996 and 33% by 2010. Thus, even a 5% conferral rate for baccalaureates in science and engineering will require substantially increased participation by such minority groups. At present, their participation is minimal. In 1988, fewer than 300 blacks and Hispanics received Ph.D.'s in science and engineering. No substantial improvement can be anticipated within the next few years. In fact, between 1976 and 1986 the percentage of black and Hispanic high school graduates going on to college declined, and both groups have significantly higher dropout rates than whites and Asians. The nation's schools must develop an environment that encourages minority students to pursue the sciences, one that is perceived as supportive and rewarding.

Concluding Remarks

Some may take comfort in the fact that conferral rates for baccalaureate degrees in science and engineering have remained roughly constant for 30 years. But any reasonable analysis of the realities of global competition in today's marketplace should be discomfiting in the extreme. The fact that the number of young people selecting science and engineering careers has not increased during a generation in which S&T pervades every aspect of our lives is nothing less than a scandal. A variety of reasons have been advanced; for example, uninteresting curricula in grades kindergarten (K) through 12 and teachers who are inadequately trained and poorly rewarded. Programs to deal with these problems have been discussed repeatedly, but few concrete steps have been taken. We need to redouble our efforts to ensure that all levels of government are committed to K through 12 programs and provide adequate support.

However, we need to do more than simply try to ensure adequate funding for programs that attract students to science and engineering. We also need to ask whether we, as scientists, are communicating, through our actions, the values that attracted us to science in the first place. Our universities take justifiable pride in the world-class research facilities on their campuses. Yet few research professors pay much attention to teacher training programs at their university, and fewer still would willingly sacrifice even a small percentage of their budget to improve such training programs.

Research universities take pride in the quality of the Ph.D. students they produce. Yet few of the research professors who bemoan the condition of precollege instruction in science would advise their graduate students to devote substantial time to the preparation of curriculum materials for grades K through 12. In addition, few advise seniors to consider careers in high school teaching.

These examples suggest the difficult choices we face in seeking to ensure the vitality of science and engineering in an era of limits. Obtaining funds to pursue even a fraction of the research opportunities on the horizon will be difficult. Finding trained scientists and engineers to further those opportunities will be a still more daunting task. There is little hope of securing the needed human resources unless we invest some of our current capital in their future.

Public support for science and engineering depends not so much on the discoveries and inventions produced, but on how closely the values of scientists coincide with those of the larger society. Those values are most evident to the public in our attitudes toward education. The title of the AAAS presidential address by Wesley C. Mitchell on the eve of World War II was "The Public Relations of Science" (*17*). Mitchell credited John Dewey, one of his mentors, with the assertion that "the future of democracy is allied with [the] spread of the scientific attitude" (*17*, p. 95). He went on to suggest what the scientists in his audience might do to act on Dewey's proposition (*17*, p. 95).

> As teachers in schools and colleges we can help thousands to develop respect for evidence. . . . We can promote general understanding of the methods and results of science through our own writings. . . . These things we should do, not as high priests assured that they are always right, but as workers who have learned a method of treating problems that wins cumulative successes, and who would like to share that method with others.

Those words, uttered on the threshold of World War II, apply with even greater force in our time as we move to the threshold of a new decade, a new century, and a new millennium.

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8. As is customary in this type of work, I use the term "projection" rather than "prediction." The latter term implies that the model's output will actually be realized, whereas the former term carries a somewhat different meaning—namely, that the model's output can be modified over time if appropriate interventions occur.
9. [redacted]
10. As noted earlier, the analyses presented in this paper focus on the natural sciences and engineering; they do not include the behavioral and social sciences (economics, political science, psychology, and sociology). Some observers believe that faculty shortages in those fields and in the humanities will be even more severe than in the natural sciences and engineering. Bowen and Sosa (*7*), for example, estimate that in the 1997 to 2002 period the candidates-to-jobs ratio for faculty positions will be 0.71 in the humanities and social sciences, 0.81 in mathematics and the physical sciences, and 1.13 in the biological sciences and psychology. As in any industry, the ideal job ratio would be roughly 1.3 candidates for each job.
11. The consequences of events associated with *perestroika* and Europe 1992 undoubtedly will influence these projections. It will be easier to recruit scientists from the U.S.S.R. and Eastern Europe to fill positions in the United States, and fewer American scientists will be involved in military research. On the other hand, Europe will become increasingly more effective as an economic power and the United States will have to increase its research investments to remain internationally competitive. No attempt has been made to model these variables, but I believe they will increase rather than decrease the demand for technical personnel.
12. K. C. Green, *Am. Sci.* **77**, 475 (1989).
13. R. C. Atkinson, "The outlook for academic employment," paper presented at the stated meeting of the Regents of the University of California on 16 February 1989 in San Francisco.
14. The Association of American Universities (AAU) has recommended that the federal government take the following actions: (i) double the number of fellowships and traineeships; (ii) increase the number of research assistantships in federal agencies supporting academic research; (iii) expand incentives for underrepresented minorities and women to earn Ph.D.'s; and (iv) restore a comprehensive investment in university research by providing expanded, flexible support for research and direct funding for research facilities and instrumentation (J. Vaughn, "The federal role in doctoral education," a policy statement of the AAU, Washington, DC, September 1989).
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17. W. C. Mitchell, in *The Maturing of American Science*, R. H. Kargon, Ed. (AAAS, Washington, DC, 1974), pp. 81–95.
18. I am indebted to W. A. Blanpied for helping formulate many of the ideas presented in this article.

1155

They're Not Dumb, They're Different

Stalking the Second Tier

by SHEILA TOBIAS

An occasional paper on neglected problems
in science education

Published by Research Corporation
a foundation for the advancement of science

Introduction

"For every complex question,
there is a simple answer—
and it's wrong."

—H. L. Mencken

To solve the nation's twin problems of a projected shortfall of science workers and general science illiteracy, many educators are proposing a massive restructuring of the curriculum and pedagogy of elementary and secondary school science. Does it all sound familiar, reminiscent of the reaction to Sputnik some 30 years ago?

While the importance of improved school science cannot be diminished and is, indeed, demanded to improve science literacy, it is not a remedy, nor does it offer hope for an immediate increase in science graduates. The author of this first of a series of occasional papers on neglected problems in science education chides members of the science professoriat for a comfortable "elsewhere" focus; for advocating K-12 reforms rather than coming to grips with the hemorrhaging of the student pipeline that occurs during the college years.

Proposed here is that science educators focus on such issues as course design, teaching and curriculum as well as on recruitment, rewards and opportunities in science. The goal would be to attract that group of able students who can do science, but select other options, a group dubbed the "second tier." By getting to get to know these students and finding ways to reverse their migration from science to other disciplines, it should be possible to stem the massive loss of potential science workers that occurs during the college years.

Such a migration reversal must take place at the several junctions at which the sciences lose potential practitioners: the transition between high school and college; the freshman year; and the midmajor, middecision points where, having completed as many as two years of college science, students change directions. If we are to truly alleviate the problems of an inadequately educated populace and a projected shortage of scientists and engineers, we must demand that no college student be allowed to leave science "without a struggle."

The author's previous research (see page 93 for a selective bibliography) focused on math anxiety and what makes college science "hard?" A technique she employed was the participation of nonscience faculty in artificially constructed college science lessons. In this first project for Research Corporation, she turns to introductory science as experienced by stand-ins for the so-called "second tier." Six graduate students and one professor, all from nonscience fields, were recruited to "seriously audit" introductory physics or chemistry. Their task: to purposefully explore their personal encounters with the courses and "classroom culture" of beginning college science. *They're Not Dumb, They're Different—Stalking the Second Tier* includes excerpts from the field notes of these seven auditors and comparable data from a study of Harvard-Radcliffe students who switched out of science courses, and from a University of Michigan study of a cohort of students in science.

"Final Speculations" asks penetrating questions about why the science community focuses on the supply of future science workers, while leaving demand to chance and the market. While most thinking people agree that the nation needs more science, we should not assume this need will translate into more paid work for scientists. Students (other than those singularly determined to be scientists) look for career opportunities, mobility, adequate compensation, and opportunities for advancement. If the nation is going to attract new recruits to science, we owe them not just a welcome, but jobs and career ladders appropriate to their abilities.

This essay will not be pleasing to all members of the science teaching community, and a few will complain of methodology that draws more from ethnology than the physical sciences. Such objections notwithstanding, most will agree that Sheila Tobias's findings are provocative and worthy of serious discussion. It is Research Corporation's aim to help probe the reasons behind the shortfall and the public lack of interest in science. If this booklet provokes discussion of how we can better teach and share the excitement of science, the public and our professions will be well served.

John P. Schaefer, Ph.D.
President
Research Corporation

Tucson, Arizona
May 1, 1990

Stemming the Science Shortfall at College

> "Who will do science? That depends on who is included in the talent pool. The old rules do not work in the new reality. It's time for a different game plan that brings new players in off the bench."
>
> —Shirley M. Malcom[1]

Everybody says it in one way or another: we need to teach more students more science. To a policy-oriented social scientist, this means we have to identify the able students who are choosing not to pursue science; find out why they are put off by science and attracted to other occupations; and, if necessary, change the recruitment, reward, and opportunity structures to match their temperaments and needs. This may involve providing not just more access, but more individual attention and support; not just more tutoring, but more meaningful and appealing introductory courses; not just more scholarships, but substantial loan forgiveness for those who decide to stay in science, and more and better job-ladders for terminal B.A.s; in short, substantive guarantees of *welcome* and *success*.

But "recruitment," "rewards," and "opportunity structures" are not the usual stuff of educational reform. So it should not be too surprising that science educators are promoting, rather, a massive restructuring of the nation's elementary and secondary science curriculum and the training or retraining of virtually everyone who teaches science from kindergarten through twelfth grade.[2]

I will argue here that, however necessary this restructuring may be, localism and the extreme diversity of the nation's 16,000 school districts will make precollege curricular change difficult to implement and much longer than anticipated to achieve. While such reform will chip away at science illiteracy and pave the way eventually for new

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[1] Shirley M. Malcom, is head of the Directorate for Education and Human Resources Programs of the American Association of the Advancement of Science. This final paragraph is taken from her *Essay*, "Who will do science in the next century?" *Scientific American*, Feb. 1990, p. 112

[2] Among these are: Project 2061 of the AAAS, a new curriculum for the elementary grades that will be appropriate when Halley's comet comes around again; the National Science Teachers' Association's *Scope, Sequence, and Coordination of Secondary School Science*; NSF's $14 million support for seven projects to develop new curricular materials for elementary school science. For a comprehensive review of the more than 300 major policy studies on mathematics and science education in the U.S. since 1983, write to Jay Shiro Tashiro, Math/Science Institute, Simon's Rock College, Great Barrington, MA 0213

recruits to science, it may not be the most efficient or effective way to meet the projected shortfall.[3] There is no question that any shortage of science workers, actual or projected, is profoundly linked to science illiteracy. Science is too little "spoken" in the nation's households and there are too few role models for young people to emulate. Nor is there any doubt that the long-term recruitment of students to science will be served by *any* improvement in the nation's educational performance. But practicably, and in the interest of cost-effectiveness, it may be better to *disentangle* the several strategies currently underway, i.e., science literacy, curriculum reform, and recruitment of future professionals to science, at least in the immediate future.

This means focusing on college.

The fact is, a very large number of American high school graduates survive their less-than-perfect precollege education with their taste and even some talent for science intact. As many as half a million students are probably taking introductory college science at some level each year. The problem is that between 1966 and 1988 the proportion of college freshmen planning to *major* in science and mathematics fell by half.[4] Even after the introductory course, the flow out of science continues seemingly unchecked. One-third to one-half of those who initially indicate an interest in science leave science well into the major, some even after completing a science degree. To stem that "hemorrhaging" of would-be science workers at the *college* level is a strategy that must be urgently pursued, along with sweeping changes in the elementary and high schools.

Why, then, has such a strategy not attracted the science community? Why the tacit approval and even preference among practicing scientists for precollege reform?[5] Some reasons suggest themselves to someone viewing the profession from outside. Reformers—and insofar as they become educational reformers scientists are no exception—are most comfortable dealing with problems that have their origins (and, hence, their solutions) elsewhere. In the case of the science shortfall, "elsewhere" is in the pedagogy and curriculum of the lower grades (where scientists have virtually no voice or influence); in the "anti-intellectualism" of the nation's home environments; in teacher-recruit-

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[3] [redacted]

[4] Kenneth C. Green, "A Profile of Undergraduates in the Sciences," *American Scientist*, Vol. 77, Sept.-Oct., 1989, p. 476. Green does not point this out, but in proportion this drop occurred in all the liberal arts disciplines.

[5] There have been efforts to study and deal with the exit of science students at college, but K-12 issues decidedly dominate the national debate. See the recent *Newsweek* cover story ("How to Teach Science to our Kids," April 9, 1990). For a sampling of college-level efforts,

ment and teacher-training (which usually occur in departments of education cut off from departments of science); even in the "negative image" of scientists as portrayed by popular culture.

There may be another reason that college science teachers look elsewhere for reform. Because they are good researchers, scientists prefer situations in which variables can be isolated and controlled. As anthropologist Sharon Traweek concludes after studying the belief systems of high-energy physicists, "Scientists long passionately for a world without loose ends."[6] For many scientists, then, it seems more logical to begin with *pure substances* (the nation's six-year-olds) and *uniform initial conditions,* than to flounder in the messy bog of motivation, attributes, and prior training exhibited by postsecondary students in their early years at college.

This may be why tackling the projected shortfall through elementary and secondary school science reform is "easier" for many academic scientists to contemplate (and to ask the nation to pay for). Dealing with the problems that aggravate the shortfall during the college years is more difficult. College retention strategies cannot, however, be left to chance. Even if—especially if—the nation achieves the massive educational restructuring proposed, tomorrow's recruit to science may *not* be of like mind and motivation as yesterday's. Nor is there any guarantee that the projected shortfall will be eliminated. Restructuring or no restructuring, we need new thinking about "who will do science" and "why," thinking that may challenge college science teachers to grapple with issues they have not focused on before. These are how to recruit, teach, reward, and cultivate different kinds of students to science, students who are *not* younger versions of themselves.

But scientists are not likely to do such rethinking so long as they continue to expect the next generation of science workers to rise, as they did, like cream to the top. This is why introductory college courses remain unapologetically competitive, selective and intimidating, designed to winnow out all but the "top tier," and why, as Eric Schocket observes in his commentary on introductory physics (see *infra*), there is little attempt to create a sense of "community" among average students of science. Even good students (Kenneth Green's "B" students)[7]

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see: The National Science Board, 1986 Report (the Neal Report); the NSF Disciplinary Workshops 1988 Reports; The Revised Curricular Guidelines from the American Chemical Society's Committee on Professional Training. Particularly relevant to the project detailed here is the focus on college courses in a Report of the National Advisory Group of Sigma Xi, entitled *An Exploration of the Nature and Quality of Undergraduate Education in Science, Mathematics and Engineering,* Jan. 1989. The authors of the report designate introductory courses in science, mathematics, and engineering as "watershed courses" and urge colleges and universities to make these more accessible, more interesting and more rewarding.

[6] Sharon Traweek, *Beamtimes and Lifetimes, The World of High Energy Physics,* Cambridge: Harvard University Press, 1988, conclusion.

[7] Green, *Ibid.*

News & Comment

Who Will Do Science in the 1990s?

The next 10 years should be a good time to be a scientist or an engineer looking for a job, but not so good for employers looking to hire scientifically trained personnel

SCIENCE IN THE '90s

Ninth in a series

ROBERT DAUFFENBACH'S crystal ball is a little cloudy today. The Oklahoma State University economist forecasts the U.S. labor supply for the National Science Foundation, and although he is working with the most up-to-date NSF econometric model, he is skeptical. The simulation predicts only 10,000 new jobs for biological scientists over the next decade—a growth rate of only 15%, no more than the increase of the work force as a whole. "I don't even believe those numbers," Dauffenbach says. The real growth rate is likely to be higher, he explains, because increasing commercial applications for biotechnology should make biology a fast-growing field in the 1990s.

[redacted] college students thinking about careers, managers at research labs or universities, and government planners. Furthermore, in spite of some uncertainties, forecasters agree surprisingly well on what the major trends of the 1990s are going to be. Perhaps the most striking will be a sharply increasing demand for scientists and engineers as the decade wears on [redacted]

For the student considering a career in science, this is good news. "The number of jobs for scientists and engineers should grow at about two times the rate of the rest of the economy," Dauffenbach says. And although making predictions for specific disciplines is tricky, it is possible to point to several likely "hot fields."

Engineers will be in great demand during the 1990s as technology plays an increasingly important role in the production of goods and services. The Bureau of Labor Statistics predicts that there will be 350,000 new engineering jobs from 1988 to 2000—a 25% rise. The NSF, working with a slightly different model, foresees a 30% jump for engineers.

But within engineering, there will be some sharp variation in job opportunities. [redacted] And then there are some fields where the predictions depend mostly on who is making them. [redacted]

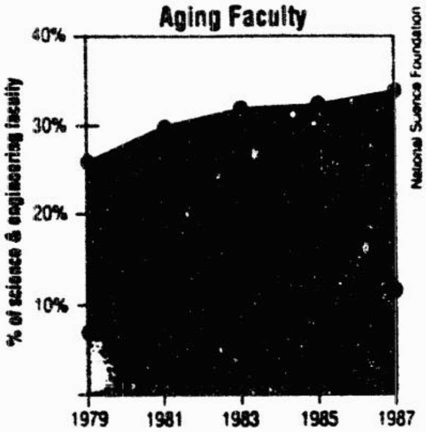
[redacted]	[redacted]	[redacted]	[redacted]
MANAGEMENT – ENGINEERING, MATH & NATURAL SCIENCES	258,000	341,000	+32%
ENGINEERS	1,411,000	1,762,000	+25%
[redacted]	[redacted]	[redacted]	[redacted]
ELECTRICAL/ELECTRONIC	439,000	615,000	+40%
[redacted]	[redacted]	[redacted]	[redacted]
BIOLOGICAL SCIENTISTS	57,000	72,000	+26%
COMPUTER & OPERATIONS RESEARCH ANALYSTS	503,000	763,000	+52%
[redacted]	[redacted]	[redacted]	[redacted]

Bureau of Labor Statistics

[redacted] This variability emphasizes how important the current political changes in Eastern Europe could be. "Our set of projections included a 15% decline in real defense expenditures," says Ronald Kutscher, associate commissioner of the Office of Employment Projections at the BLS. "This may underestimate the shift away from defense." Since 10 to 20% of the country's engineers are involved in defense work, "the markets for some engineers are likely to soften in the 1990s," he says.

A college student who wants to go into science instead of engineering will have to be a little pickier about choosing a specialty.

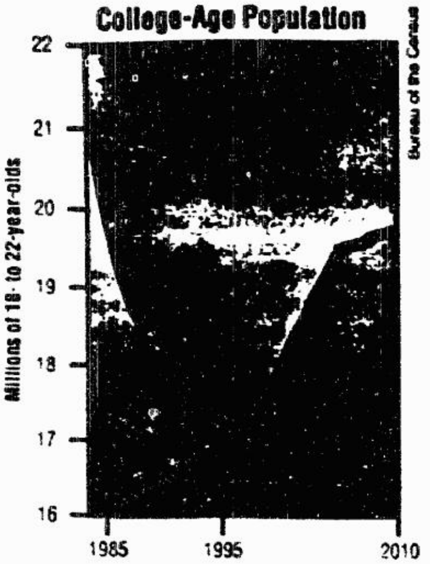
Aging Faculty



National Science Foundation

[redacted] New technologies will require new materials, and salaries for trained materials scientists—now in short supply—can only go up. Within this field, the hottest topics are likely to be electronic and optical materials, superconductivity, composites, and materials analysis using such tools as synchrotron radiation, lasers, or scanning microscopes.

For those who prefer DNA to moon rocks, the expected biotechnology boom—the NSF model aside—should generate plenty of jobs in the 1990s. The BLS predicts 15,000 new jobs for biological scientists—a 26% increase.


College-Age Population

Bureau of the Census

And the biggest growth industry of the last decade should be big for the 1990s, too. According to the [redacted] "I think the boom [in jobs] now will be with computer scientists seeking out problems in other areas," says Stanford provost James Rosse, who explains that many of the departments at the university are developing their own computer expertise. Computer specialists can expect to find job openings in a number of fields besides computer science, he says.

This increasing demand is the good news. The bad news is that the crystal ball doesn't say where all these scientists and engineers are going to come from. According to Richard Atkinson, chancellor of the University of California at San Diego, [redacted] Although supply is much harder to predict than demand, there seems to be good reason to worry about not having enough trained workers in the late 1990s and beyond.

The shortage of Ph.D.'s could hit especially hard at colleges and universities, where a "retirement wave" may hit at about the same time as a sharp increase in student enrollments. Over the past 10 years, the average age of faculty steadily increased, and many of the teachers who were hired in the 1960s to teach the Baby Boomers will reach retirement age in the 1990s. This wave will break at an awkward time: college enrollments, which have been falling over the past decade, are expected to start back up in 6 or 7 years as the children of the Baby Boomers reach college age.

[redacted]oreign students have taken up the slack. In 1988, foreign students with temporary visas earned 18% of all life science Ph.D.'s awarded by U.S. colleges and universities, 30% of all physical science Ph.D.'s, and a staggering 45% of all engineering doctorates. The result: a surge in the percentage of jobs going to foreigners, since about half of all temporary residents earning doctorates stay in the United States after they graduate.

The effect has been particularly noticeable among engineers. In 1985, two-thirds of all postdoctoral positions went to noncitizens, and about half the assistant professors under 35 were temporary residents. In the general engineering work force, more than one-third of all Ph.D. positions were held by foreign-born workers. In 1988, the National Research Council reported that foreign students are crowding U.S. students out of positions in graduate schools and foreign engineers are taking jobs that would otherwise go to U.S. citizens. The council also worried that foreign-born teachers with poor English skills may be hurting university education. The situation is similar though not quite as dramatic in the natural sciences.

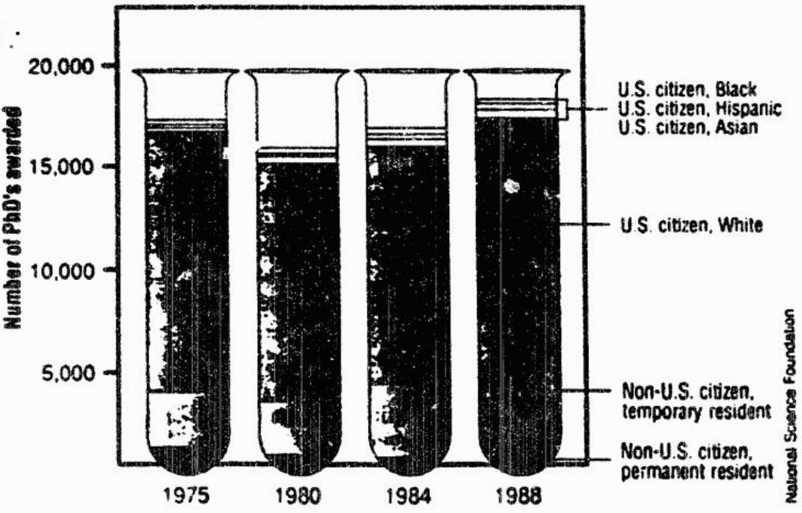
The growing dependence on foreign-born students and workers makes people particularly nervous because if those workers decide to go home, the United States could wind up with some disastrous labor shortages. "We have got to do a better job of growing our own," says Kay Hanson, director of the Consortium on Financing Higher Education, a Washington, D.C.–based group of 32 research universities and liberal arts colleges. "My guess is that [foreign] students who in the last 20 years would have stayed here may find it is equally rewarding to go somewhere else" because of improving economic and political conditions in the rest of the world.

But if the United States is going to recruit from its own ranks, it will want to look outside the group that has been the main source of scientists and engineers so far: white males. From 1985 through 2000, only 15% of the net new entrants to the work force will be white males. The rest will be women, minorities, and immigrants. For that reason, many people have argued that these are the people who should be recruited into technical careers. The trends today, however, suggest that that effort will be an uphill struggle at best.

Over the past 20 years, women have increased their participation in science and engineering dramatically. They now earn 45% of the bachelors degrees and 30% of the Ph.D.'s in those areas. But that progress seems to have ground to a halt.

"The percentage of women earning bachelors degrees in natural sciences and engineering stopped rising in 1982," says Betty Vetter, executive director of the Washington, D.C.–based Commission on Professionals in Science and Technology. And the percentage of women Ph.D.'s has been nearly steady for the past few years. What happened, Vetter explains, was that the number of women going to college rose dra-

Science and Engineering PhD's: A Changing Chemistry



National Science Foundation

matically in the 1970s, which led to women earning more degrees in every area, but the percentage of women choosing science as a major changed little. Furthermore, most women who go into science avoid the traditionally "masculine" fields. Females get only 8% of the Ph.D.'s in physics, 14% in computer sciences, and 15% in mathematical sciences. They are far more likely to go into the life sciences (35% of all Ph D.'s) or the social sciences (half of all doctorates, including 60% of all psychology Ph.D.'s).

The reasons for such choices may be social, cultural, financial—even genetic. But whatever the underlying cause, the pattern doesn't seem likely to change soon. "I believe the reason lies in the socialization of children almost from the day they are born," Vetter suggests. "I don't see it changing appreciably until we change society." The gender makeup of the class of 2000 will probably look much like the class of 1990.

There are at least some bright spots in the picture of women in the sciences, but this is not true of underrepresented minorities—blacks, Hispanics, and American Indians. These groups have failed to come into the system in sizable numbers, and nothing seems likely to happen in the 1990s to increase the flow of underrepresented minorities into science much past the trickle that it is now (see box).

The one success story among minorities is the rise of Asian-Americans. If both U.S. citizens and foreigners with permanent visas are included, Asian-Americans account for about 6% of all Ph.D.'s in the natural sciences and 16% in engineering. Asians have long been well represented in the U.S. scientific work force, but they are too small a percentage of the total population to solve a possible shortage by themselves.

So the question of where the United States will find the scientists and engineers to take it into the 21st century doesn't have a simple answer. Yet surprisingly, representatives of industry don't seem too worried about it. "If you simply look at the demographics, it looks pretty bad," says Lloyd Friend, director of research and development personnel for AT&T Bell Laboratories. "But the supply of science and engineering students is really driven by students' views of job opportunities. If you create the demand, you'll have the supply."

Robert Armstrong, Du Pont's manager of professional staffing in Wilmington, Delaware, describes a study that compared the percentage of high school students going into engineering with the average starting salary of engineers. "The correlation is just beautiful," he says—when salaries rise, more students go into the field. The percentage can double in 5 to 6 years, he found out.

The upshot of all these numbers seems to be that the scientists and engineers coming into the work force in the 1990s will be a lot like those in the 1980s. The main difference is that there should be more of them. But that will happen only if high school and college students figure out that it will be worth their while to move out of business majors and prelaw and premed and into science and engineering. So pass the word Tell them you heard it from a crystal ball

■ ROBERT POOL

A Lost Generation?

It's been more than 20 years since the civil rights movement convinced this country that black students had the same rights to a good education as white students. And for more than a decade, many colleges and universities have been aggressively recruiting minority students and doing their best to keep them in school until they graduated. So you would expect that the number of minorities earning degrees in science and engineering would be rising sharply, right? Wrong—by a long shot.

The number of black males earning Ph.D.'s is actually less now than 20 years ago. And although the number of black women receiving doctorates has risen slowly, it has not made up for the decline among the males. From 1979 to 1988, the total number of blacks becoming Ph.D. scientists and engineers dropped 20%; they now earn only 1% of all doctoral degrees in natural sciences and engineering despite making up 11% of the working-age population. In certain fields, it is next to impossible even to find a black candidate to interview for a job opening. In 1988, for example, only one black U.S. citizen earned a Ph.D. in mathematics and only one in computer sciences.

More Hispanics have gone into the hard sciences, but the numbers are nothing to crow about. They currently account for about 2% of all natural science and engineering Ph.D.'s, much lower than their 7% of the working-age population. On the other hand, the number of Hispanics earning doctorates has been steadily growing, particularly among women, and should continue its slow increase.

The solution to these problems won't be easy, because the difficulties clearly don't begin in college or graduate school, but much earlier. The average score of black students taking the Scholastic Aptitude Test (SAT) in 1988, for example, was 200 points less than whites and Asians (on a range of from 400 to 1600 points). Hispanics scored on the average 130 points less. In a 1986 test of mathematical proficiency, 17-year-olds were judged on whether they could perform multistep problem-solving and algebra. The small percentage of high school students who can do such analysis are the ones most likely and most able to go into science and engineering in college. Among the students tested, 7.6% of the white students performed at this level, while only 1.2% of Hispanics and 0.3% of blacks did.

Ironically, the few minority students capable of doing science or engineering at the university level are highly sought after. Major universities recruit them aggressively, then work to keep them in school with various retention programs. Even small schools are getting into the act. In one innovative program, the University of Maryland–Baltimore County recruited 19 black males who had excelled in high school and who had an interest in science, offering them each 4 years of tuition, room and board, and books, as well as a personal computer. In exchange, the 19 agreed to get degrees in science or engineering and continue on to Ph.D.'s or M.D.'s. Vice provost Freeman Hrabowski, who developed the program, says the idea was to push the best students to excel and, in so doing, provide role models for other black males.

And after graduation, minorities find that both academia and industry come calling. "The competition is very ferocious," says Stanford provost James Rosse.

So the demand is there, but the supply is lagging. And increasing the supply of minorities in science and engineering is likely to be a long, arduous process, says Betty Vetter, executive director of the Commission on Professionals in Science and Technology. "We're losing a whole generation of children, and probably their children too," she says.

■ R.P.

ACBM

Summer 1
Vol. 2 No

Cementing the future

National Science Foundation Center for Science and Technology of Advanced Cement-Based Materials

Outreach Matters

by Alison Good,
ACBM Outreach Coordinator

This article is the first in a continuing series about ACBM education and outreach [illegible]

As the most recent addition to the staff of the Center for Advanced Cement-Based Materials, I welcome the opportunity to communicate with you and other interested members of our growing audience. I have chosen to name this column *Outreach Matters* to address both the goals and value of outreach in terms of philosophy and programming.

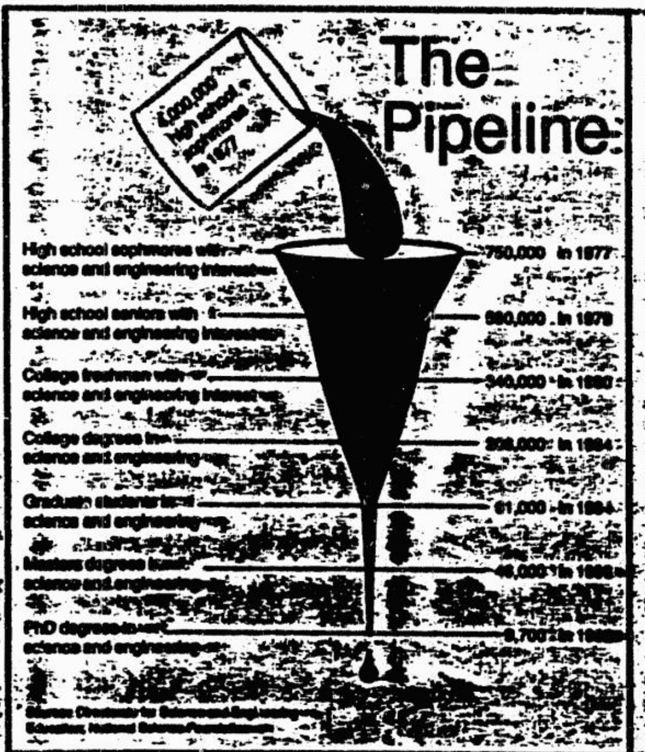
The main goal of outreach has always been to ensure that the results of research find their way into the country's knowledge and technology base. Traditionally this has been accomplished by publishing and presenting. In 1989 the National Science Foundation (NSF) instituted Science and Technology Centers (STC) to improve the mechanism for increasing the transfer of knowledge among sectors of society and ensure a solid foundation for attracting undergraduate and graduate students into science and engineering careers, with special emphasis on minorities and women. [illegible]

continued on page

OUTREACH continued from page 1

Recent statistical findings by the U.S. Department of Labor and the NSF have shed light on the scope and scale of potential human resource problems which may broadly influence future U.S. knowledge and technology bases in science and engineering:

1. By the year 2000, it is estimated that 85 percent of the incoming labor force will be women, minorities and immigrants.
2. Too few American students are pursuing science and engineering degrees (see The Pipeline graph).
3. By the year 2010, the U.S. will face shortages of 300,000 to 700,000 scientists and engineers.



Source: Directorate for Science and Engineering Education, National Science Foundation

There is evidence to suggest that outreach efforts must be expanded and strategically targeted if we are to improve the general understanding of science and technology for our citizenry, increase the number of Americans preparing for scientific and engineering professions, particularly minorities and women, and keep our economy growing in an internationally competitive world.

This is the challenge that ACBM outreach must meet. It must encourage collaborations which leverage Center faculties, students, facilities, and equipment. In addition to the traditional transfer of knowledge and technology which the Center generates to other related scientific and technical communities and institutions, outreach will also need to promote communication with and educational opportunities for people in education, industry and commerce, government and society at large.

Our ACBM outreach philosophy is being shaped by: 1) the nature of our research, 2) the structure of the ACBM Center as an NSF Science and Technology Center, and 3) the natio [illegible] focus on human resources [illegible] science education. Lack of [illegible] entists trained in [illegible] multidisciplinary aspects of c ment-based materials and [illegible] glect of the subject in universi curricula have contributed [illegible] the current gap in cement tec nology. The establishment [illegible] the NSF of a Science and Tec nology Center for Advance Cement-Based Materials co solidates the renaissance th appears to be occurring in c ment research. To this end, [illegible] Center will develop broad ou reach strategies to address thr areas: student recruitment, [illegible] ulty enhancement, and com munication with commerce an industry.

Student Recruitment

Addressing the growin shortage of scient [illegible] and eng neers, the Center will have [illegible] additionally seek resources [illegible] crease undergraduate research opport nities, especially for minorities and women; 2) train a significant number [illegible] scientists in multidiscip [illegible] cement-based materials [illegible] programs which enrich [illegible] ences for high school [illegible] students; 4) explore possib [illegible] with junior high school teachers in sc districts serving minority [illegible]

A WORD FROM THE DEAN

Understanding the Engineering Shortage

Theodore A. Bickart

At the Society of Automotive Engineers Off-Highway and Powerplant Congress and Exposition in Milwaukee, Wisconsin, last September, I was one of four panelists asked to discuss a topic of great personal concern—the predicted shortage of engineers in the 21st Century.

To ready myself for the discussion, I prepared a paper which I titled, "Human Resources in Engineering: The Real Need." I would like to share with you the salient points of my presentation.

[redacted]

If, in fact, these estimates are correct, [redacted]

This is clearly an impossible task. The only way to resolve this dilemma is to educate the engineers we do have to be more effective and efficient.

We must also work to make certain the engineers of tomorrow will be educated in at least the same numbers as they are today. To maintain our ranks, it is necessary to expand the educational opportunities for females and underrepresented minorities in engineering.

Let me share with you some actual data. According to the Bulletins of the Engineering Manpower Commission of the American Association of Engineering Societies, the nation is currently producing about 68,750 BS degree, 26,500 MS degree and 5,000 PhD degree engineers annually.

Of these totals, the underrepresented minorities—African Americans, Native Americans and Hispanics—constitute about seven percent of the BS degree, 3.5 percent of the MS degree and 1.5 percent of the PhD degrees engineers produced annually.

The statistics on female engineers are similarly low: 15.25 percent BS, 13.5 percent MS and 8.75 percent PhD degrees are conferred each year.

Just as women represent half the population, the trend is such that minorities, predominately underrepresented minorities, will constitute about half of those of college age early in the next century. About 40 years from now, they will comprise half the population in the United States.

It seems to me the most effective and efficient way to sustain, maybe even increase the ranks of the professional engineer is to recruit more female and underrepresented minority students to the study of engineering at each degree level and to retain them to the completion of the degree.

When it comes to women, recruitment is our biggest challenge. In 1986, for example, 15,000 women began studying engineering. They represented about 15.25 percent of the nation's freshman engineering class.

Four years later, about 10,500 had completed their baccalaureate degrees. Their retention rate was high—70 percent. That is essentially the retention rate for all engineering students.

If engineering programs around the country can maintain these commendable retention rates while dramatically increasing the numbers of women recruited to engineering study, we will make significant strides in our effort to meet the engineering needs of the next century.

Underrepresented minority students present a different challenge. At present, we are moderately successful at recruiting freshman engineering students from among the underrepresented minorities. In 1986, 11,500 minority students comprised about 10.5 percent of the nation's freshman engineering class.

Four years later, however, only about 4,250 or 6.25 percent of those freshmen had completed their baccalaureate degrees. That makes the retention rate of these students approximately 37 percent.

It is clear from these figures that the retention of underrepresented minority students—students who have already shown an interest in and aptitude for engineering—is of paramount importance.

While solutions can be summed up into two words, recruitment and retention, the implementation of these solutions is awesome and wide-ranging. It involves everything from the promotion of science, engineering and technology scholarship in the country's day care centers and K through 12 grades of school to the easing of costs required to pursue advanced degrees in engineering.

It is generally important to the success of recruitment and retention efforts at the college level to have well identified programs with professional directors for our female and underrepresented minority students. To these students, there is a tangible commitment to their success. The message is simple: We want and expect them to succeed.

At the College of Engineering, we have such programs. In subsequent issues, I will define the facets and goals of our Engineering Equal Opportunity Program, one of the oldest minority assistance programs in the Big Ten, and our women's assistance program.

Self-interest as well as national interest demands we take decisive action to expand our diminishing ranks with capable, qualified female and underrepresented minority engineers. ■

IEEE Spectrum, Fall 1990

Currents

Dr. William C. Taylor with General Syed S. H[illegible]ain

College Programs Span the Globe

This summer the College of Engineering officially expanded and strengthened its international academic outreach programs.

In August, Dr. William C. Taylor, professor and former chairman of the Department of Civil and Environmental Engineering, signed a cooperative agreement with General Syed S. Hussain of the Military College of Pakistan, in Risalpur, for the awarding of master's degrees in civil engineering to select Pakistani students.

At the same time, the Department of Mechanical Engineering welcomed home its first four Rockwell International Scholars. The scholars are junior class members who participated in the department's nine-year-old overseas study program in Aachen, West Germany, and then traveled to Frankfurt to complete a paid internship at the Rockwell-Golde manufacturing plant. This is the first year Rockwell International has offered such an opportunity.

Both programs aim to prepare students to compete effectively in a world market through student and faculty exchange, and collaborative research. "With these programs, we are trying to create a new generation of engineers. Engineers who possess technical excellence as well as cultural awareness and proficiency in a foreign language," says John J. McGrath, professor and acting chair of the Department of Mechanical Engineering.

McGrath initiated the Aachen program in 1981 and today plays an active role on its faculty advisory committee. The program originally involved sending ten to twenty undergraduates each spring quarter to Aachen for 10 weeks of mechanical engineering classes, field trips to various German industries and supervised research at the university.

In 1984, German graduate student began traveling to MSU to conduct engineering research associated wit their thesis work. Since the prograr founding, almost 150 MSU undergra uates and nearly 60 German graduate

Continued on back page

Q181

57% of U.S. Math Doctorates Going to Foreigners

By MALCOLM W. BROWNE

Of the 933 doctorates in mathematics awarded in the United States in the last academic year, only 43 percent went to American citizens, the lowest percentage on record.

A survey published this month by the American Mathematical Society said that from July 1, 1989, to June 30, 1990, the number of Ph.D. degrees in mathematics increased by 3 percent over the preceding year, and by 15 percent over the average of the last four years. But only 401 of the recipients of doctoral degrees were United States citizens.

In recent years, foreign students have won increasing shares of advanced United States degrees in engineering, mathematics and several sciences. The latest survey suggests that the trend is continuing.

The participation of blacks in advanced mathematical training also appears to be declining, the report said. In the previous year, nine American blacks received doctorates in mathematics, a slight increase, but in the period covered by the latest survey, only four were awarded the degree. The proportion of women awarded doctorates in mathematics also fell slightly, from 24 percent to 22 percent.

Dr. Edward A. Connors, a director of the survey who is at the University of Massachusetts at Amherst, said, "We are disappointed that the increases in awards to women and blacks reported last year were not sustained."

The survey also indicated that when new holders of doctorates take jobs in teaching or research, they cannot expect quick wealth; median starting salaries for new doctors of mathematics are $32,000 for men and $32,500 for women.

Fewer women and blacks get diplomas in advanced math.

Mathematics is a core subject on which all sciences depend, and educators predict that the decline in doctoral degrees awarded to Americans in these subjects will jeopardize the nation's economic prospects.

A year ago, the National Science Foundation reported the results of a study concluding that by the year 2006, the United States would face a shortage of 675,000 scientists and engineers.

One of the problems, the foundation reported, is demographic. White men now make up 80 percent of the scientific and engineering work force in this country. But by the year 2010, white men will account for less than one-third of the college-age population.

If greater proportions of women and nonwhite men cannot be recruited for advanced mathematical, scientific and engineering programs, the lack of trained professionals will severely hobble national technologies that sustain economic health, the study concluded.

11/23/90
Chicago Tribune p34

Study: Foreign students get most math doctorates

New York Times News Service

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SPECIAL REPORT: ENGINEERING CAREERS

'90s employment: some bad news, but some good

The current job outlook differs radically with the country, with economic conditions, with national policy, and with engineering field

Over the past year in the United States, nearly a quarter of a million engineers and other employees in high-tech companies have lost their jobs. An undetermined number were electrical engineers.

Hardest hit have been big computer and aerospace companies. Widely publicized defense cutbacks are only part of the story. In the general civilian economy, layoffs have resulted from company mergers and decreases in the market demand for certain major electronic products (such as minicomputers)—not helped by increasing energy costs resulting from Iraq's invasion of Kuwait and the seizure of its oil fields. Moreover, by late this year, in many circles discussants were bringing up the dreaded R-word: recession. And since late 1989, based on leading economic indicators, the IEEE's Engineering Manpower Committee has been projecting that the employment outlook for EEs will grow worse before it gets better, hitting bottom early next year.

Canada also seems to be suffering the beginning of a recession—in part perhaps because its economy is strongly linked to that of the United States. In Ontario alone during the first nine months of this year, 132 companies have eliminated nearly 19 000 jobs, compared with 11 500 for all of last year.

Times are also somewhat tough even in the formidable newly industrialized country Taiwan. Its heavy reliance on imported crude oil from the Persian Gulf has hiked operating expenses, while economic difficulties in the United States have decreased demand for all electronic products.

Meanwhile, some engineers in such nations as Britain, France, Germany, and India seem never to have had it so good—although there are conflicting signals. With the high-tech plans for a unified European market after 1992, the unification of Germany requiring the reconstruction of the industrial infrastructure of the former East Germany, and the Indian Government's encouragement of computer and software industries in an effort to ready its economy for the 21st century, many company leaders feel new engineers are not being trained fast enough. For the short term, these countries are even considering the importation of nonnational engineers to fill the demand. But over the long term, some analysts predict that even France and Germany may face a slight rise in unemployment. As yet unclear are the effects and ultimate significance of the recently announced layoffs of 7000 employees from the Italian computer and office equipment giant Ing. C. Olivetti & Co. S.p.A., 7500 workers from the French computer manufacturer Groupe Bull, and up to 55 000 people by Philips NV of the Netherlands.

Trudy E. Bell Senior Editor

Japan's economy is hovering between boom and bust. Although some slowing of demand there for high-tech products is pinching the revenues of major companies, company managers so value the experience that comes only with lifelong employment that they are taking every measure possible to avoid laying off engineers and other employees, even if in the short run cutbacks might improve the ubiquitous bottom line.

Despite the overall grim picture with large companies in the United States—particularly those dealing with hardware and those in the Northeast—high-tech companies with fewer than 1000 employees are still growing, some very rapidly. Indeed, so many of them are still creating jobs that, at least for now, they seem to be somewhat mitigating the effects of the massive cuts at their big-corporation counterparts.

Obviously, the global picture of trends in engineering employment is complex. To the best of anyone's knowledge, what is the current outlook for engineers and their jobs—both over the next year and through the decade to 2000? What engineering industries are harder hit than others—and which are more robust? How can engineers prepare career and job strategies for survival—for both their companies and themselves?

This special report, the product of an *IEEE Spectrum* editor and seven international correspondents, draws on both statistic and individual case studies to ascertain the level and implication of worldwide disruptions and opportunities.

1. Job security, soft in North America. has strong spots in Europe and Asia

How safe is your job? The answer seems to depend on wher you are. Some countries view employees as expendable resourc to be cast aside when times are tough and acquired when economies improve; others see them as a long-term capital investmen to be protected during the bad times in order to be ready wit depth and expertise for the good times.

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nical people will increase," said Philip A. Lapp, president of Philip A. Lapp Associates, an engineering consulting firm in Toronto, and president of Radarsat International, a US $400-million project to build and launch a synthetic-aperture radar satellite and to market remote-sensing images.

This demand for engineers will increase "at the same time we are seeing decreased enrollment in our engineering schools," elaborated George Lazano, a spokesman for the Canadian Council of Professional Engineers in Ottawa. Lazano believes that this could lead to a shortage of some 45 000 engineers by 2000.

Similarly, in Taiwan, in spite of immediate problems, most experts still forecast that over the next few years jobs in electro-optics will surge. Firms are ramping up to commercialize electro-optic technology recently developed by the state-sponsored Industrial Technology Research Institute in Taipei. These technologies, including laser printers, laser-driven facsimile machines, and scanners, should begin reaching the market early next year.

In the United States, the strongest prophecies of a shortfall of natural science and engineering (NS&E) graduates since 1988 come from the National Science Foundation's Division of Policy Research and Analysis. In a paper dated summer 1990, the NSF predicts that, based on a "cumulative reduction in production of NS&E bachelors degrees below the average annual number graduated during 1984-86...the cumulative shortfall of bachelors to the year 2006 would be about 675 000" [Fig. 9].

"I don't have much use for shortage predictions," remarked Richard A. Ellis, director of manpower studies for the American Association of Engineering Societies (AAES) in Washington, D.C. In the October 1990 issue of AAES's *Engineering Manpower Bulletin*, Ellis questions how applicable the NSF projections are for engineers because of several of its assumptions: engineers are not separated from natural scientists despite the two professions having different demographics; no allowance is made for changes in the economic outlook that could reduce the demand for engineers; and the 1984-86 benchmark used to judge the magnitude of the projected demand is an all-time historical peak, and thus may be biased on the high side over time.

"Regardless of the state of the economy, there are always going to be surpluses and shortages in certain fields," said Daryl Chubin, a senior analyst for the U.S. Congress' Office of Technology Assessment, Washington, D.C. For example, he noted, despite a drop in the U.S. college-age population, it is possible that the supply of people trained in science and engineering will not decline at all if older people return to school, if a larger fraction of existing students choose those fields, or if non-U.S. nationals continue to represent 25-45 percent of scientific graduate students. He cited a 1985 OTA report, *Demographic Trends and the Scientific and Engineering Work Force*, which concluded: "Given the problems with forecasting supply and demand for scientists and engineers, predictions of shortages based on such forecasts should be treated with considerable skepticism."

5. Estimates of defense-related employment by occupational group for 1977, 1980, and 1985

Occupation	1977	1980	1985
Total (thousands)	1801	2087	2897
Managers	190	224	318
Professionals, technical	240	310	437
Marketing, sales	73	84	116
Administrative support	306	355	490
Services	143	183	261
Mechanics, installers	85	99	133
Precision production	114	134	191
Machine setters, operators	186	194	269
Handworkers	146	174	243
Construction trades	57	58	78
Transportation operators	94	94	125
Helpers	92	96	128
Others	75	83	110
Percent distribution			
Total	100.0	100.0	100.0
Managers	10.5	10.7	10.9
Professionals, technical	13.3	14.8	15.1
Marketing, sales	4.1	4.0	4.0
Administrative support	17.0	17.0	16.9
Services	8.0	8.8	9.0
Mechanics, installers	4.7	4.8	4.6
Precision production	6.4	6.4	6.6
Machine setters, operators	10.3	9.3	9.3
Handworkers	8.1	8.4	8.4
Construction trades	3.2	2.8	2.7
Transportation operators	5.2	4.5	4.3
Helpers	5.1	4.6	4.4
Others	4.2	4.0	3.8

Note: Occupational employment is based upon wage and salary jobs, while industry employment also includes the self-employed and unpaid family workers and is somewhat higher.
Source: David K. Henry and Richard P. Oliver, *Monthly Labor Review*, August 1987

4. Strategies for survival—helping self and company

Clearly, for the next year or so in the United States and Canada, employment opportunities for engineers will tighten. Long-term prospects are not so clear—no one has yet invented an effective crystal ball. Japan, Taiwan, and even Europe—with its booming demand but also massive layoffs—have somewhat mixed short-term prognoses. India seems to be a seller's market.

So, what can you do to cushion yourself and your company in a shrinking economy, and maximize chances for success?

Put not your trust in projections

First, neither an optimist nor a pessimist be about the future demand for engineers—because whole new industries might spring up. "At the beginning of the 1970s, with the aerospace recession, things looked awful, but with the advent of the microcomputer, the end of the 1970s boomed in an unprecedented way," said the AAES Engineering Manpower Commission's Ellis.

Beware especially of predictions of shortages, and thus the overoptimistic demand for engineers, warned the IEEE Manpower Committee's Rivers. "There is no such thing as a shortage in a free-market economy," he asserted. "If a commodity is in short supply, prices get adjusted so supply is rationed out to people who are willing to pay for it." He urged job seekers to look behind the simple numbers. For example, low salaries are one reason that engineering jobs can go begging in the German public sector and in India in spite of high unemployment. If the demand for engineers were as strong as companies and governments say, he cautioned, salaries would rise accordingly.

At the same time, do not lose heart over the near-term reports of downsizing, as there is no agreed-upon way of "translating layoffs into unemployment," said IEEE Fellow Haddad. Many people with engineering backgrounds find satisfying work in nonengineering careers, such as finance or education, he noted.

The consensus of all was that young people contemplating an engineering career should base their decision on personal preferences and job satisfaction, not on numerical projections.

Think small

If an engineer is laid off from a large company, he or she "might consider working for a small to mid-sized company," suggested CorpTech's Parker. He attributes the strength of companies employing fewer than 1000 employees to the fact that, with fewer

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Heading Off a Ph.D. Shortage

Government and universities must provide more support, and establish reforms, to ensure adequate levels of intellectual manpower.

Unless prompt action is taken, a sharply increased demand for Ph.D.s in the United States will outstrip a comparatively level supply before the turn of the century. Industry, government, and universities will be pitted against each other in a battle for this critical human res[illegible], and the entire nation will pay the price—diminished leadership and competitive strength.

In the natural sciences and engineering, the nation could face an average annual shortfall of 9,600 Ph.D.s between 1995 and 2010, **according to projections made by Richard Atkinson (chancellor of the University of California, San Diego), based on recent analyses by the National Science Foundation.** He anticipates shortfalls rising from about 3,000 in 1995 to approximately 14,000 in 2010.

Atkinson's projections are the product of three factors:

- Increases in "replacement demand" resulting from the [illegible] **documented aging of U.S. academic, industrial, and government scientists and engineers, a consequence in part of the surge in hiring during the post-Sputnik period of growth in American science;**
- **enrollment-driven increases in new faculty positions**, a virtually certain consequence of the known increase in the college-age population occurring in the latter part of this decade;
- **and a 4 percent growth rate in the number of new Ph.D.s hired by industry and government**, reflecting the assumption that at least modest increases in the level of R&D will be necessary to maintain economic growth and international competitiveness.

As Atkinson points out, the lessening of tensions with the Soviet Union and the opening up of Eastern Europe will reduce the number of U.S. scientists and engineers absorbed by defense R&D. It may even ease recruiting of Soviet and Eastern European scientists for positions in this country. However, any reductions in demand from these changes will likely be more than offset by **the competitive pressures exerted by the consolidation of the European Community**, the continued

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technological advances by the countries of the Pacific Rim, and new proposals to expand U.S. commitments to address domestic and global environmental challenges.

William Bowen (president of the Andrew W. Mellon Foundation and past president of Princeton University) and Julie Ann Sosa (a recent Princeton graduate) have conducted a thorough analysis of the academic labor market that not only confirms Atkinson's projections but shows that **faculty shortages will occur in all the arts and sciences. Their work is based on extensive documentation of faculty-replacement demand, enrollment trends, shifts in the popularity of fields of study, and changes in student/faculty ratios.**

These analyses are the most recent work on Ph.D. supply and demand, but there is a considerable body of supporting evidence from other studies. **And although projections on such a scale are necessarily imprecise, the plausible margin of error cannot begin to erase the shortages that are anticipated under current trends.**

If such shortages are allowed to occur, the impact will be felt not only in higher education but also in industry and government: More than 70 percent of engineering Ph.D.s and nearly 65 percent of physical science Ph.D.s now seek employment in nonacademic sectors, about three-fourths of them in industry and the remainder primarily in government. Across all fields, 50 percent of Ph.D.s seek employment in nonacademic sectors.

Toward an optimal, sustainable supply

There are three ways to reduce the projected shortages: intervene to increase supply, intervene to reduce demand, or rely on the labor market to equilibrate supply and demand.

Several mechanisms could be used to reduce demand: capping the growth in R&D; increasing the use of non-Ph.D. faculty, scientists, and engineers; increasing student/faculty ratios; and restraining access to higher education. But none of these mechanisms is very appealing.

Reducing demand by limiting access to higher education runs counter to a fundamental tenet of national higher education policy and would surely be unacceptable. Some adjustment in student/faculty ratios may be a feasible response for some colleges and universities, but a substantial increase in these ratios would impair the quality of education, a price few would be willing to pay. Similar arguments apply to shifting to non-Ph.D. faculty, scientists, and engineers.

And if the United States fails to sustain at least modest growth in R&D—and in the supply of Ph.D.s required by that growth—the consequences for our economic competitiveness are likely to be severe. Our major economic competitors have been steadily increasing their investments in R&D, and there is every reason to expect that they will continue to do so. Scaling back R&D support also would have serious implications for advances in such areas as health care and national security.

Relying solely on market forces creates two problems: The full effect of a market response would almost certainly occur too late; and there is no reason to expect that a market adjustment alone would provide an optimal, sustainable supply. A substantial increase in enrollment, in response to an increased demand for Ph.D.s, would not occur much before the appearance of that demand in the mid- to late 1990s. And because of the long time to degree, the resulting Ph.D.s would not appear for nearly a decade. Furthermore, current nonacademic market forces provide strong disincentives for college graduates to pursue doctoral programs. Precisely those graduates whose talents and accomplishments qualify them for doctoral programs are the job candidates most highly sought in prevailing markets.

Market forces will undoubtedly continue to dominate both demand and supply. That is appropriate to the American setting. **But we have tried relying on the labor market as an unaided allocating mechanism during the progressive disengagement of the federal government from doctoral support over the past 20 years (described below), and the result is a current shortage of Ph.D.s in several critical fields and projected shortages in virtually all fields.**

Because the growing demand for Ph.D.s is generated by the expansion of activities that benefit the nation, the most positive course is to increase the supply of people needed to carry out those activities. Increasing supply does not carry the productivity costs associated with reducing demand, and it can provide a more timely and balanced response than relying on the market alone.

A set of relatively low-cost policies to increase supply, if they are put in place now, can help us adapt to the conditions that lie ahead and avoid the need for more expensive and less effective crash programs when the crisis is upon us. Three categories of actions can produce effective results:

- *Financial support*, properly packaged, can increase both the quantity and the quality of students enrolling in doctoral programs.
- *Expanding proven incentives* for increased participation by students from underrepresented groups can increase the number of women and minorities who earn Ph.D.s.
- *Institutional reform* of university policies governing doctoral programs can reduce time to degree and high attrition rates.

This is not the best time to call for increased federal investments, but support for doctoral education is a federal responsibility.

The ups and downs of federal investment

The past 30 years have witnessed a period of massive infusion of funds into doctoral education, followed by an extended disinvestment. The results show both how federal policy can produce desirable outcomes and how mistakes in the magnitude and timing of that support can have undesirable consequences.

Large-scale federal support for graduate study began with the passage of the National Defense Education Act (NDEA) in 1958—a reaction to Sputnik and to the anticipated need for additional college faculty to teach the baby boomers. Additional fellowship and traineeship programs were established by NIH, NSF, NASA, and other federal agencies. (Fellowships are grants awarded directly to students by the granting agency; traineeships are block grants awarded to institutions or departments, who use the funds to provide support to students they select.) Combined with support through research assistantships, the number of federally funded graduate-student stipends increased from 1,600 in 1954 to approximately 80,000 in 1969.

Over this period, the percentage of graduate students in science and engineering receiving federal fellowships and traineeships increased from 14 percent to 56 percent. The growth in federal support was accompanied by rapid growth in the number of Ph.D.s produced—from just under 10,000 in 1960 to over 26,000 in 1969.

This period of growth was followed by a precipitous decline in federal programs, **prompted in part by an overproduction of Ph.D.s at the time**. Between 1970 and 1975, federal funding for fellowships and traineeships dropped from $430 million to $201 million (in constant dollars), and the decline continued into the 1980s. In the sciences, it was partially offset by an increase in research assistantships, from 21,400 in 1974 to 36,600 in 1988, but the humanities and social sciences fared comparatively poorly throughout the period of growth as well as during the decline: Little support outside the NDEA fellowship program was available to these disciplines during the growth period, and they lacked the buffer of research assistantships during the decline.

Support for doctoral students through the GI Bill has largely disappeared as well. Following its inception in 1966, the Veterans' Educational Assistance program helped support the graduate study of nearly 750,000 students who served in armed forces between 1955 and 1976. Its demise was a major loss, aggravating the elimination or reduction of other fellowship and traineeship programs. In addition, the Tax Reform Act of 1986 made stipends taxable, thus diminishing the effective levels of support provided through remaining programs.

In the past several years, the federal government has established new fellowship and traineeship programs in the Departments of Education, Defense, and Agriculture. **NSF has embarked on a five-year doubling of its highly regarded graduate fellowship program.** Despite these recent initiatives, however, federal support for doctoral education remains well below the level of support provided 20 years ago. In FY 1989, the federal government spent about $215 million to support approximately 13,000 new and continuing graduate students through fellowships and traineeships. Including an estimated 37,000 research assistantships, **federally funded stipends totaled 50,000, about 60 percent of the peak number of 80,000 stipends funded in 1969.**

The federal government plays an important role in making loan capital available for graduate study. Federally subsidized loan programs can provide an effective source of financial assistance to augment primary sources of grant support. However, dependence on loans is generally considered inappropriate for doctoral students, who are preparing for careers that all too often provide only modest incomes.

At present, nearly half of the financial support for doctoral study comes from students, spouses, loans, and family contributions. That fraction is too high—the decline in the number of U.S. citizens earning Ph.D.s demonstrates that many individuals are unable or unwilling to carry so much of the financial burden of completing a doctorate. Although students and their families should finance their *undergraduate* education to the extent that they are able, it is not wise national policy to expect the best college graduates to forego regular employment and to finance advanced education as well. Particularly in science and engineering, such a policy encourages college graduates to turn away from doctoral study and toward the other options available to them.

Any significant increase in support for doctoral education must come from the federal government. Corporate patrons are unlikely to make larger investments in doctoral education when the return on investment to any specific corporation is necessarily indirect and uncertain. Similarly, state governments are unlikely to increase their investments, because the benefits of doctoral education are primarily national in scope. Foundations are reluctant to provide comprehensive, long-term support, which is incompatible with their issue-specific operation. And although universities have tried to fill the growing gap—they now provide the largest share of financial assistance other than that provided by doctoral students and their families—universities have few additional resources they can bring to bear on the problem.

This is not the best time to call for increased federal investments, but support for doctoral education is an appropriate federal responsibility because it supplies a national resource: the country's teachers, scholars, scientists, and engineers.

A complete federal strategy

The doctoral education enterprise grew too large too fast in the 1960s and early 1970s. Excessive growth produced a crowded job market, particularly in the humanities and social sciences, where the market was largely confined to the academic sector. In response, however, the federal government overreacted by dismantling wholesale the programs that had contributed to the surge in Ph.D. production.

The federal government's withdrawal of support needs to be reversed, with the projected Ph.D. shortages giving federal reinvestment added urgency. But it would be a mistake to try to scale federal support precisely to the dimensions of the expected shortages: Demographic and market projections, as well as the manpower programs designed to respond to them, are inherently imprecise. In any event, it is not the federal government's role to ensure that every Ph.D.-level job has a Ph.D. ready to fill it. Rather, we believe that it is the responsibility of the federal government, as a prudent investor in a social enterprise of enormous value, to help enough of the most able students to pursue Ph.D.s in order to ensure that the enterprise does not deteriorate for lack of adequate talent. What is needed, therefore, is a federal investment strategy that helps to reduce the impending shortages and evolves into a balanced, sustainable pattern of support.

Federal policy should be designed to encourage a steady infusion of able students into doctoral programs in all disciplines, although there may be an added emphasis on certain strategic areas. For example, both the Congress and the administration see a greater national interest in the natural sciences and engineering than in the humanities and social sciences. Federal policy can be expected to continue to emphasize support in these areas as it does now (about 75 percent of federally funded fellowships and traineeships are in the sciences and engineering).

Federal agencies that have a direct stake in graduate education should maintain strong fellowship or traineeship programs appropriate to their missions. **Comparative studies show that students aided by such programs finish their degrees more quickly, and are more likely to receive additional research-grant support, than other students of comparable ability.** Students supported on teaching assistantships have longer times to degree, and students supported by loans and personal income have the longest times to degree of all.

Most federal agencies with a clear interest in doctoral education already administer some form of fellowship or traineeship program. Thus, the basic structure of an effective matrix of programs is already in place; in fact, it needs only two additions for completeness:

Federal agencies should maintain strong fellowship or traineeship programs appropriate to their missions.

Double the number of fellowships and traineeships. The 13,000 new and continuing fellowships and traineeships currently funded by the federal government should be doubled to 26,000. Doubling the number admittedly sounds arbitrary, but it is a realistic, achievable goal that, combined with additional adjustment mechanisms (explained below), could significantly reduce the projected shortages.

Increase the level of financial support provided by fellowship and traineeship programs. To provide effective incentives, stipends must offer an adequate living allowance. Subsistence levels—some stipends are as low as $7,000 per year—are not enough. Given the career alternatives available to science and engineering students, annual stipends in these disciplines should be in the range of $14,000 to $16,000. Fellowship and traineeship programs should also cover a reasonable portion of the actual institutional costs of education, either through payment of tuition and fees or through an institutional allowance that increases with the costs of education. An annual institutional allowance of $8,000 to $10,000, though well below any estimate of the cost of graduate education in science and engineering fields, would at least cover a substantial fraction.

The costs of these changes in federal support would not be minor. If new fellowships and traineeships average $26,000 annually (stipends of $16,000 and cost-of-education allowances of $10,000, taking the upper limit of the suggested ranges to account for inflation), then 13,000 new and continuing awards would cost $338 million at steady state. And if 13,000 existing stipends should be increased by $3,000 and institutional allowances by $2,000 (as very rough estimates of the average increases necessary to bring existing support levels up to those proposed above), the aggregate cost would be another $65 million.

The total cost of $403 million per year is a large expenditure, in an absolute sense, and certainly under current budgetary conditions. But viewed as an investment in the people needed to conduct our national R&D, it is a minuscule expenditure, less than three-tenths of one percent of the estimated $150 billion the United States will spend on R&D in FY 1990.

Agencies supporting university research should also support at least one graduate-student research assistant for each grant initiated by an individual investigator. Such inclusion not only provides effective apprenticeship training, but also enhances the quality of the research by tapping the graduate students' creative energy and fresh perspectives.

More minorities and women

To meet the growing demand for Ph.D.s, a much larger proportion of minorities and women must be attracted into doctoral education. Several private foundations have focused on this problem, and universities are aggressively pursuing new and expanded recruitment and retention programs. These efforts are producing results: At one university, sustained faculty involvement has produced in one year a doubling of minority doctoral students admitted; at another institution, a systematic retention program has produced an 87 percent completion rate for minority doctoral students.

These institutional programs are expensive. They require added faculty time for individual monitoring and advising, and additional courses and seminars tailored to individual needs. Federal matching grants for recruitment and retention programs—both to develop new initiatives and to replicate successful ones—would allow universities to expand these efforts significantly.

The federal government can also help by providing predictable, multiyear graduate support and by funding "early-identification" programs (which award research internships to talented minority undergraduate and high school students). The Department of Education, NSF, NIH, and NASA are among the federal agencies with strong minority fellowship programs; NIH and the Department of Education administer highly effective early-identification programs for minority undergraduates.

Federal agencies should also collaborate with universities to increase the number of minority graduate students supported as research assistants. Too often, minorities are not drawn into the informal networks of faculty and students that are so important to success in doctoral programs. By remaining isolated in coursework, they fail to begin the involvement in research necessary to complete their dissertations. In such circumstances, research assistantships may be one of the best ways of drawing minority students into contact with colleagues in research settings.

As a new, government-wide initiative, each federal agency that funds research should provide supplemental funding to faculty investigators who successfully recruit minority research assistants. These programs should be administratively independent of the primary project grant application and funding process, permitting faculty to bring minority research assistants into their research programs quickly and simply when the opportunity arises.

Women have made significant progress in terms of financial support and degrees received, but they are still underrepresented in most disciplines, particularly the physical sciences and engineering. NSF has begun a new predoctoral fellowship program to provide increased incentives for women to continue their engineering education at the graduate level. Other agencies that fund research in fields in which women are underrepresented also should provide such incentives for women to earn Ph.D.s.

Undergraduate research internships should be particularly effective in increasing the pool of women prepared for doctoral study in science and engineering. Successful undergraduate research experiences could help replace present attitudinal barriers with the interest and confidence to continue work in these fields.

Institutional reform

Increased federal support of doctoral education, although necessary, is not sufficient: there is much that graduate schools must do for themselves. The persistent underrepresentation of women and minorities, and indeed much of the decline in the number of U.S. students enrolling in doctoral programs, can be traced to what is taking place—or failing to take place—on campus.

For example, it is taking progressively longer to earn a Ph.D.: the median time required to complete the degree increased from 5.3 years in 1968 to 6.9 years in 1988. Attrition has also increased: Comprehensive data are not available, but most estimates place it at about 50 percent, and it may be as high as 80 percent in some fields of the humanities. **There is ample evidence that lax practices and unenforced policies within universities contribute to such high attrition and prolonged times to degree.**

In October 1990, the Association of American Universities (AAU) and the Association of Graduate Schools (AGS), comprising the graduate deans of AAU's 58 member institutions, endorsed a policy statement recommending institutional policies that will improve the efficiency and effectiveness of doctoral programs. Among their recommendations are the following:

Graduate-student teaching. Its primary purpose should be to prepare effective teachers, and it can be accomplished by a progression of teaching experiences—a modest number of them—accompanied by instruction in teaching methods and assessments of teaching performance. But things have gone too far: Graduate students are teaching more undergraduates, for more hours, and in more courses. In fact, teaching has become one of the principal contributors to lengthening time to degree. Too many graduate students become caught in a financial vise: Teaching is their only means of support, and their departments have economic and other incentives to make generous use of them as teachers.

Research assistants. Although graduate students are a key component in the academic research environment, the principal purpose for the performance of graduate-student research is pedagogical: They need to learn how to perform research, demonstrate that ability in their dissertations, and then move on. Students should not be kept on for the benefit of a faculty investigator's project, or to generate more publications, or to learn yet another new research technique. Students are almost always better off expanding their research expertise as salaried Ph.D.s than as underpaid graduate apprentices.

Faculty advising. Advice and support from mentors are among the most important factors in determining the success of students' doctoral education. Faculty advisors must assist students in choosing coursework that meets their needs and interests without unnecessarily extending their programs. They should also encourage students to move on to seminars and laboratory work that will lead to dissertation topics, and to define dissertation topics that are realistic in scope. Good advisors already do these things; to make sure that they happen more routinely, departments should establish explicit requirements for all faculty advising.

Truth in advertising. Departments should have written, well-publicized standards for expected student performance. To bring actual performance into accord with expectations, graduate students' work should be formally evaluated and the results shared with the students and their faculty advisors, who should respond appropriately.

Lax practices and unenforced policies within universities contribute to high attrition and prolonged times to degree.

Departments with well-structured graduate programs, including clear expectations of graduate-student performance and faculty responsibilities, have lower attrition rates and shorter completion times than departments whose programs lack these attributes. The AAU/AGS report offers specific suggestions for how to establish and maintain such programs. We hope that presidents, chancellors, graduate deans, and other administrators will work with departments and faculty on each campus to implement those recommendations in ways appropriate to their specific institutional settings.

Meeting the needs of the nation

What impact will these recommendations have on the projected shortages? Because of the interplay of numerous variables, none of which can be quantified with accuracy, it is obviously impossible to give a precise answer. Nonetheless, some illustrative approximations can be offered:

On the supply side, we can estimate the impact of a doubling of fellowships and traineeships. Assume this is accomplished by a program of 13,000 new and continuing four-year awards, with 3,250 new awards being funded each year. Assuming further that 80 percent of the recipients earn their Ph.D.s—roughly the experience of the NSF fellowship program—then the supply of Ph.D.s will increase by 2,600 per year.

If such a program were begun in 1992, most of the 2,600 new Ph.D.s would enter the market around 1998. Atkinson projects a shortfall that year of about 7,000 science and engineering Ph.D.s for all markets—higher education, industry, and government. For the 5-year period 1997–2002, Bowen and Sosa project a shortage of just under 5,500 faculty in the humanities and social sciences—approximately 1,000 faculty per year. Adding this to Atkinson's projection produces an estimated shortage of 8,000 Ph.D.s in 1998 for all disciplines and all markets.

Doubling the number of federally funded fellowships and traineeships would thus eliminate about a third of the projected shortages. That may seem like an insufficient response, but a number of additional adjustment mechanisms would also come into play: expanded support through research assistantships, new initiatives for women and minorities, changes in institutional policies to reduce attrition and time to degree, and perhaps some adjustments in demand as well. Market forces will supplement these mechanisms to help balance supply and demand.

The history of federal support for doctoral education demonstrates that the government can quickly and effectively increase the quantity and quality of doctorate recipients. And we do not have to start from scratch in order to avert the presently anticipated shortfall: The components of the necessary policy are largely in place. Strengthening existing programs and filling gaps in support can provide the incentives to increase the number of talented students—with special attention to minorities and women—enrolling in doctoral programs. Meanwhile, universities themselves must move aggressively to strengthen their policies supporting doctoral education. In this way, the United States can substantially reduce the projected Ph.D. shortages, thereby helping to meet the human-resource needs, and the well-being, of the nation.

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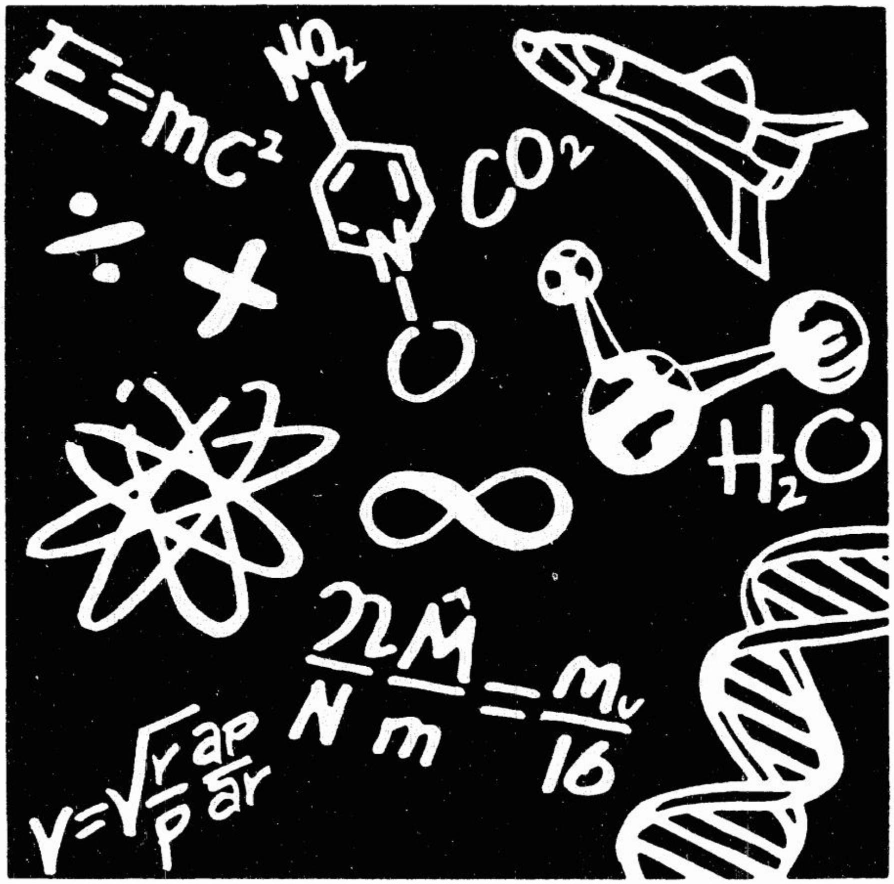
BY THE YEAR 2000:

FIRST IN THE WORLD



Report of the

FCCSET Committee on

Education and Human Resources

February 1991

Teacher preparation is also an issue. The American Association for the Advancement of Science concluded that few elementary school teachers have adequate preparation in science and mathematics before they begin to teach these subjects. Leading professional associations of mathematics and science educators have established standards for coursework preparation for teachers. By their estimates, only the following percentages of teachers meet these standards:

33% of elementary school teachers (science)
18% of elementary school teachers (math)

22% of middle school teachers (science)
14% of middle school teachers (math)

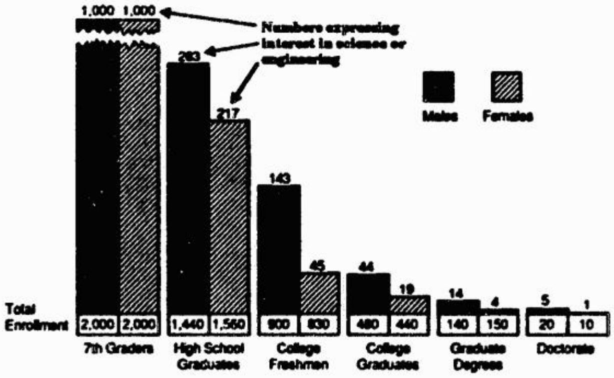
29% of high school teachers (biology)
31% of high school teachers (chemistry)
12% of high school teachers (physics)

This problem is compounded by the fact that too often, teachers are required to teach out of their fields and work with outdated or inadequate instructional materials in science and mathematics. Because teachers have little contact with the practicing scientific community, they are frequently unable to tie real-life applications to the basic scientific concepts they must teach. If we are going to improve student performance by the year 2000, we must significantly improve mathematics and science instruction well before the end of the decade. By bringing them closer to cutting-edge science, innovative curriculum and materials, Federal agencies can help prepare teachers so that they can communicate the excitement of science to their students.

Workforce/Scientific Competitiveness

A Nation at Risk and the many education reports that followed also warned that without a growth in student interest and ability in science and technology, America's world marketplace competitiveness in these fields would be in jeopardy. At similar risk would be the premier position of America in scientific research and development. As large numbers of those who entered the scientific workforce after World War II begin to retire, insufficient numbers of students are moving through the science pipeline to take their places.

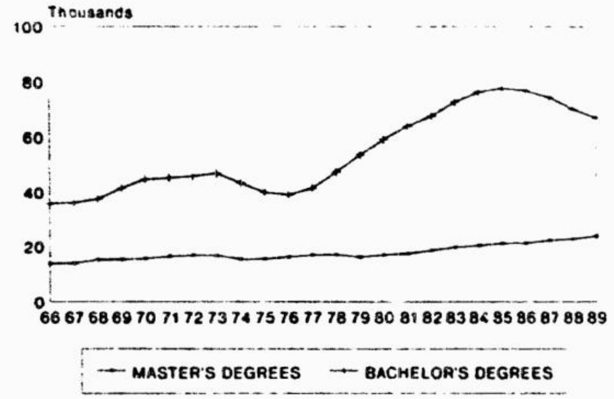
Figure 1
The Science Pipeline
Pool of Potential Scientists and Engineers Among U.S. Students



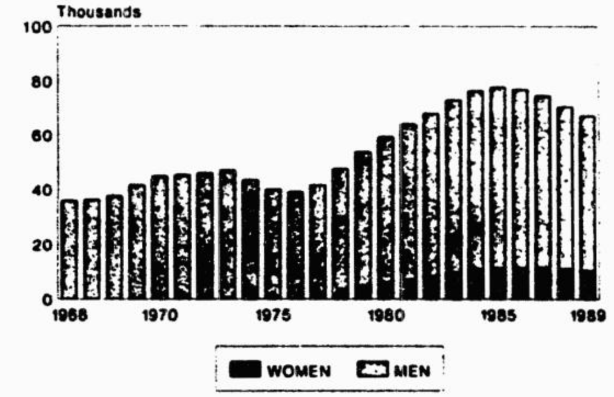
Source: National Science Foundation

If trends in American education continue on their present course, studies indicate that this country will not be able to produce enough scientists and engineers to meet its workforce needs. As Figure 1 illustrates, by the time children are in the seventh grade, fully half declare no interest in science. At the other end of the science pipeline, only six of every 4,000 seventh graders (five men and one woman) will ultimately receive a Ph.D. in science or engineering.

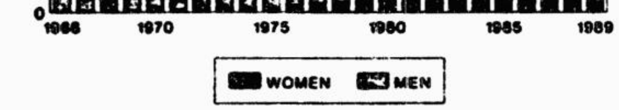
Figure 2
Engineering Degrees, 1966-1989



Engineering Bachelor's Degrees, 1966-1989



Engineering Master's Degrees, 1966-1989



Source: National Science Foundation

Figure 2 indicates a recent four-year decline in engineering bachelor's degree recipients, which is expected to be reflected at the master's level in the near future. Figure 2 also shows the low level of participation by women in these degree programs. In addition, the number of entering freshmen planning to major in engineering has dropped by 25% since 1982.

As a result of these and other factors, America's once-impressive lead in science and engineering personnel may begin to falter. Japan, for example, has doubled its technical workforce in the last two decades and, with half the population size of the United States, trains almost as many engineers as we do each year. Federal resources can help build a stronger technical workforce and maintain American inventiveness and discovery.

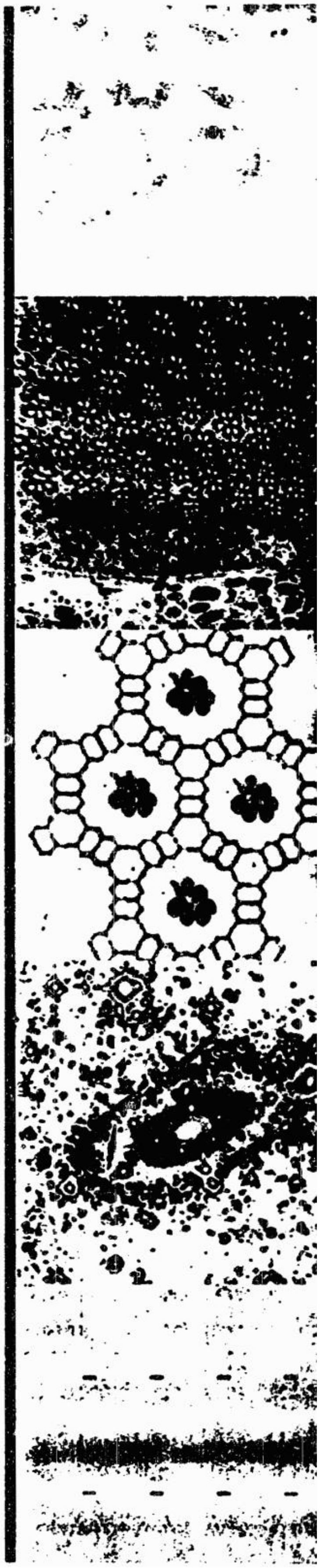
Underrepresented Groups

The problem of keeping students in the science pipeline is even greater for women, persons with disabilities and minorities underrepresented in science and technology, who, with foreign nationals, will comprise 85% of the net new entrants into the American workforce between now and the year 2000 (Figure 3). These individuals, who traditionally have not been part of the technical workforce, will be called upon to replace the decreasing percentage of white males seeking engineering and technical jobs. Today, only 8% of bachelor's degrees in science and engineering are awarded to blacks and Hispanics (20.2% of the total population combined); together, these minorities currently earn only 4% of all science and engineering Ph.D.s. At the turn of the century, minority students will account for more than 40% of our elementary and secondary school population. The Nation must take steps to

Supplement to SCIENCE

SCIENCE:

THE END OF THE FRONTIER?



A Report from
Leon M. Lederman, President-Elect
to the Board of Directors
of the
American Association
for the Advancement of Science
1333 H Street, NW
Washington, DC

January 1991

Why Keep Science Healthy?

How much does all of this matter to the nation-at-large? Given that low morale is a problem for the science community, why should the rest of the nation care? Scientists are, after all, a privileged class far better off than many in our society, and besides, there are already more crises around today than our overloaded national consciousness can handle.

The answer is, of course, that science pays. It is impossible to imagine modern society without the fruits of 400 years of scientific research. An extensive literature documents the returns to the economy generated by expenditures on science and technology. One has only to examine the ingredients of our GNP to see that a large fraction is derived from the results of the scientific research of the past 60 years or so.

Economists have estimated that for every dollar spent on the Apollo program in the 1960s, seven dollars of economic activity was generated in the American economy. More recently, economist Edwin Mansfield of the University of Pennsylvania studied the rate of return on investments in academic research. His work covered 76 major firms in seven industries: information processing, drugs, metals, electricity, chemicals, instruments, and oil. His assumptions are conservative but his result is startling: the annual social rate of return on investments in academic research is no less than 28 percent.

The tasks which are faced by American science and technology today are crucial as never before to the well being of our nation. They include:

- providing the basis for new industry to enhance the quality of life of our citizens, while extending those benefits to regions and groups that have not yet shared in them;
- improving the general health of the population while containing the costs of medical care;
- understanding the complex circumstances surrounding ecological and environmental issues and providing guidance to policymakers in these areas;
- developing alternate sources of energy and substitutes for scarce natural resources; and
- enhancing our culture by expanding our understanding of the universe and humanity's place in it.

To carry out these daunting tasks in an ever more competitive world, we will need more scientists and engineers. Yet demographic projections—such as those cited by Richard Atkinson in his 1990 Presidential Address to the AAAS—tell us that we are falling short of producing the required number of Ph.D. scientists and engineers by about 10,000 each year. Huge deficits in the number of technically trained personnel (estimated by some at up to 700,000) are expected in the first decade of the 21st century.

I am aware that such projections have large uncertainties, but I should also point out that they may be underestimated because they fail to take account of the new demands that will be placed on science and technology by environmental problems, energy and natural resources, and the needs of developing nations. Given that graduate education depends so strongly on research funding, the finding that faculty members are cutting back on the number of students they train means that the current funding situation can only exacerbate future problems in human resources for science and technology.

I'm rather bewildered. I believe that I'm one of the best young theorists in the country. Without a doubt, I've [illegible] for the most successful group of graduate students in my field. Yet my NSF single-investigator funding is [illegible] from four students to none. In the past two years, my efforts to avert this disaster have been fruitless. For obvious reasons, I'm forced to change my style of research. In the next two years I'm shifting a large part of my efforts to workstation software development, for which there is support from private industry.

—Associate Professor of Physics, Cornell

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EDUCATION

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SCIENCE EDUCATION: A CALL TO ACTION

Only five percent of adults say they understand basic scientific concepts or issues of science policy, more than 70% want curbs on scientific activities, and only half of our 17-year-olds believe science is even useful. We must reverse these trends if the U.S. is to compete successfully in the years ahead.

③

by H. Eugene McBrayer

THE state of science education is a critical issue for the future of our nation. Can our education system prepare young people for productive technological careers? Can it continue to produce the high-caliber scientists and engineers needed to maintain strong competitive performance? More broadly, can it help the American people understand the challenges in science and build a consensus for needed public policies?

Simply asking these questions reveals doubts, but there also is hope, and we never should forget that. For example, in March, 1989, a morning TV program featured three high school science students who had won Westinghouse scholarships—a young minority woman interested in social sciences, a mathematician, and one who did an animal study on the distribution of nerves.

What impressed me even more than their brainpower was their shared sense of the *enjoyment* of science. To them, it's fun, and they're right. Science is stimulating. To question, investigate, discover, apply what you discover, and contribute is the spirit of science. It's what education is all about.

Our challenge is how to communicate the excitement and the stimulation of science. Of course, I am particularly interested in encouraging young people to study chemistry and chemical engineering. We must help them finance their education and teach them how to enrich their job experiences so they can build on their schooling and mature into responsible citizens and members of the science community.

Industry alone can't solve the nation's education dilemma or the social and economic problems behind it. These need to be solved by government at every level, business of every kind, the education profession itself, and by all of us, individually and collectively. This list also includes consumers, who need to be better educated and informed. Nonetheless, the chemical industry and those in it have a necessary part to play, and we can and must be more effective.

Before we can hope to interest young people in our profession, we have to admit that our credibility isn't what it should be. Places like Love Canal, Times Beach, and Bhopal have become associated with great human suffering caused by man-made chemicals. Combined with issues like hazardous waste, toxic air emissions, and global warming, they've eroded the chemical industry's standing around the world.

Today, everybody is dealing with the fruits of our technological success, including chemicals. Since World War II, science and technology have produced enormous benefits. To the public, however, these benefits have been accompanied by new and unprecedented hazards. This has changed public expectations of chemical companies. My industry is very good at what it does, but it has to get better—fast and publicly.

If the chemical industry has been winning the technological war, we've also been losing some very important battles for the public's understanding and good will. Individual companies and industry associations continually have put forth reasoned responses to the accusations made against us, but reasoned responses don't make good TV sound bites. Our communications efforts haven't met with much success, but we'll keep trying. The public needs to hear our side. More importantly, people need to see that we mean business. It's what we do—and how the public *perceives* what we do—that counts.

If the chemical industry's reputation is low, the entire education system in this

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Mr. McBrayer is president, Exxon Chemical Company, Darien, Conn.

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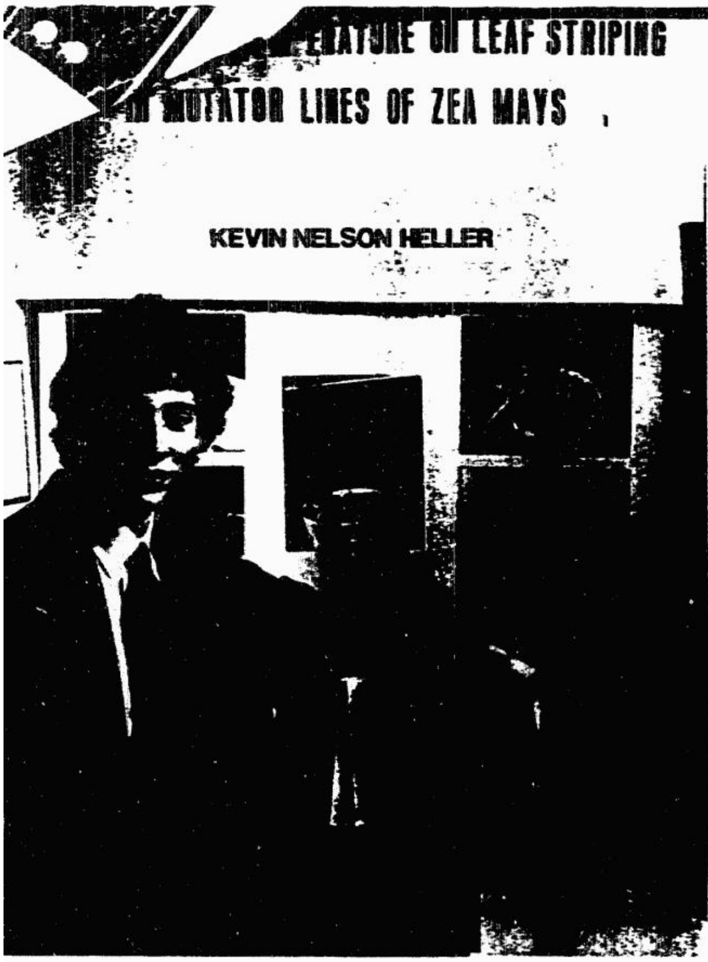

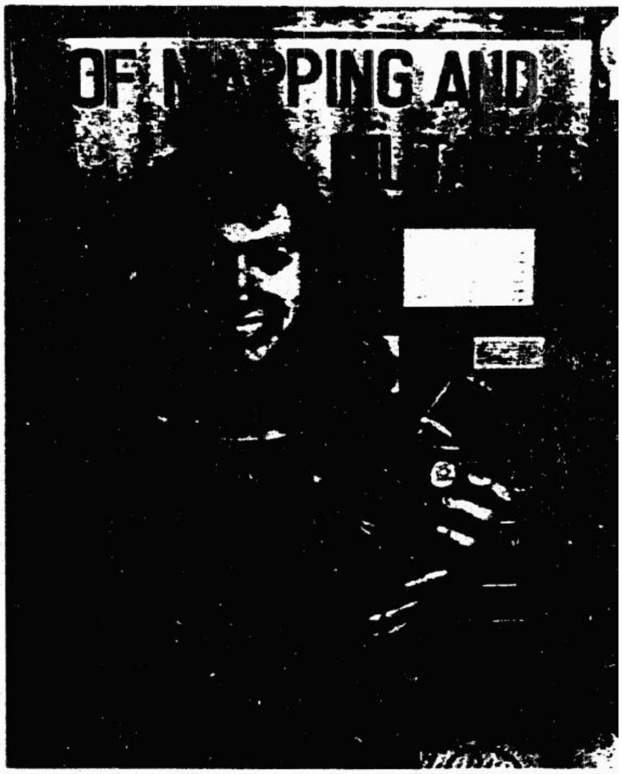

Kevin Heller, Half Hollow Hills High School West, Dix Hills, N.Y., and S. Celeste Posey, North Carolina School of Science and Mathematics, Durham, two 1989 Westinghouse Science Talent Search winners, demonstrated that American high schools can produce high-caliber science students.

country is even worse off. John Silber, president of Boston University, provides a good example of how things have changed over the years. He tells us that, more than 100 years ago, the U.S. had a system of elementary and secondary schools that were "far more serious in intent and successful in execution than almost any present-day American school." He notes that even small-town high schools in the 1850's required several years each of chemistry, algebra, English, university arithmetic, physiology, Latin and other foreign languages, philosophy, rhetoric, history, geometry, geography, elements of criticism, and botany. Reading and spelling were required daily, declamation and composition frequently. Between times, many children had to milk the cows and bale the hay. Moreover, you usually could find them in Sunday school each week.

Contrast that with so many of our urban schools today. The students have to run the gauntlet of drug pushers and rip-off artists to get to class. As one inner-city mother expressed it in a magazine article, "Before you try to fix any problems the kids are having in the classroom, you'd better realize that . . . their greatest challenges begin both before and after they leave school."

Political and economic problems, combined with deteriorating social and educational standards, are leaving us with very serious consequences. For example:

- One out of every four teenagers drops out of high school. Of those who do graduate, 25% have the equivalent of only an eighth-grade education. Put those two statistics together and we've just accounted for one-half of the high school-age youths in this country today.
- More than 20,000,000 adults are functionally illiterate. This means that nearly one-fourth of the American labor force lacks the reading, writing, and math skills to hold a decent job.
- About 25% of the children under age six live in poverty. For society and ourselves as individuals, that's tragic.

Shortages ahead

Long-range predictions are always chancy. Nevertheless, evidence is piling up that we could be facing a serious shortage of scientists in the decades ahead. A [illegible] National Science Foundation [illegible] by [illegible], by the year 2010, this nation may be short 560,000 scientists and engineers.

Where will the educated people with science backgrounds come from in the years ahead? Here, too, the statistics are not encouraging, particularly for the chemical industry. For instance, a study conducted by Jon Miller of Northern Illinois University showed that only five percent of adults say they understand basic scientific concepts or issues of science policy, more than 70% want curbs on scientific activities, and only half of our 17-year-olds believe science is even useful. In the face of these perceptions, how will voters be able to make informed judgments about the growing number of issues that science must help solve, including waste disposal, air and water cleanup, public health, and even safe use of household chemical products?

Over the long term, there are other consequences. The inability to understand fundamental scientific concepts, see the value of science in their lives, and understand science policy options are turning young people away from science and engineering.

Fortunately, the very seriousness of these problems is attracting some long-overdue attention to the secondary schools. Without students who possess a solid educational underpinning, colleges inevitably must lower their standards to accommodate the youth they get. We can not tolerate such a national calamity.

A consensus finally is emerging about education reform. Schooling must be improved significantly. Math and science especially need to be upgraded. A primary objective is to create a pool of qualified scientists and engineers for the future. We also must have a more knowledgeable public that consumes science and technology and more informed and understanding government leaders.

It is not too early for this consensus. We must hope it is not too late. Today, the best of our scientific elite is being rivaled by Europe and several Pacific Rim nations, especially Japan. Even more telling, the average scientific education of our workforce, including the technological sector, also is equalled by these nations. In short, we are losing our edge. This presents a competitive challenge that we must take into account now, because we certainly will face it in the future.

The consensus for education reform has been building for several years. State governments, which have the primary responsibility for education, have taken the leadership bit between their teeth. In addition, Washington is moving toward a more active role. George Bush's desire to be known as the "Education President" reflects this new concern.

Local, state, and national government must get out in front with real leadership, but they can't do it all, any more than business or the chemical industry can. What's needed is an active partnership among government, industry, educators, and communities. It would help very much if the slower elements of this partnership were encouraged actively—that is to say, prodded—by a populace newly awakened to the dimensions of the education problem. This is where business—every company, including those in my own industry—comes in.

Because the safe manufacture, distribution, use, and disposal of chemicals are so important, my industry is setting new standards in effective responses to these issues. Under the leadership of the Chemical Manufacturers Association (CMA), a number of self-regulating programs are now in place that require chemical companies to assist communities to plan for, and respond to, any emergencies involving chemicals. Beyond those actions, the CMA has decided that the industry's performance must be improved greatly across a broad range of activities and products. From this came a groundbreaking initiative called Responsible Care: A Public Commitment.

The basic commitment to the public is that every CMA member company will improve its health, safety, and environmental performance throughout the life cycle of the chemical process—from research to production, from transportation to waste management, and from use to disposal. This can not be done piecemeal. Therefore, it's not a voluntary initiative. Every CMA member company has to make the commitment and take the actions necessary to bring it about.

Responsible Care is built on 10 guiding principles that require every member chemical company to make health, safety, and the environment top priorities in all they do. From these principles come specifics called codes of management practice, which spell out how companies can achieve the guiding principles and keep improving their performance.

These initiatives are designed to show that the chemical industry is responsive and responsible by holding ourselves to the highest standards of performance. They are *action* initiatives. For member companies, the codes of practice must be incorporated into all our operations and ways of doing business.

Industry acts

The chemical industry also needs to intensify its efforts to improve science education. To the extent the industry can help, it is responding with a larger and more varied number of programs to help teachers, students, and the public understand chemicals and the chemical industry.

One of the most ambitious is the American Chemical Society's $35,000,000 Campaign for Chemistry, designed to stimulate interest in chemistry and science among children and adults. One key subset is an innovative high school course that focuses on chemical issues at the community level.

At Exxon Chemical, we think this program is imperative, and the Exxon Education Foundation has made a $1,000,000 grant to help support it. DuPont, Dow, Monsanto, Union Carbide, and others also have come forward with leadership grants.

The Chemical Manufacturers Association is moving quickly and effectively to improve public understanding of our industry's role, products, and performance. Two CMA initiatives in particular deserve mention. The Chemical Education for Public Understanding Project is a grassroots education project for middle schools and community groups. It's intended to develop greater public awareness, knowledge, and understanding of chemicals and how they interact with our lives.

The other initiative is Science Screen Report, which includes seven videotapes and classroom guides on science and technology. This is given free to about 2,500 junior and senior high schools in nearly 1,200 communities and is underwritten by about 300 corporations.

Another TV course, aimed primarily at non-chemical majors in two-year colleges, is called "The World of Chemistry." That world is explored all the way from molecules to the flows of energy through the biosphere. Financial support for this project comes from Exxon, Dow, DuPont, Eastman Kodak, the PPG Foundation, and the American Chemical Society.

These are just a sampling of the programs that chemical companies are putting together or supporting. They have some important qualities in common: they're unbiased and objective, don't just hand out the party line, and provide useful materials that help people think for themselves and reach their own conclusions about the roles of chemical science and technology today.

Some of these programs are aimed at a more general audience. They focus on parents, community groups, and non-scientific professionals such as judges and lawyers—those who have to make important decisions on scientific issues.

By themselves, these efforts certainly won't solve our education challenges or turn public opinion around, but they're a good beginning. They must be refined, expanded, and coordinated to have the greatest positive impact.

All of us—business people, the chemical industry, and everyone concerned with the nation's quality of education—need to give, do, and understand more. We obviously can't wait for our education problems to self-correct. We have to be activists. The future of our industry and our nation depends on how thoroughly and effectively science is taught.

We need quality education in all disciplines, especially, in my view, the sciences. However, we must understand that this takes time and work. The programs we initiate or support certainly will not wipe out scientific illiteracy overnight. They won't persuade large numbers of students to take up chemistry as a career, turn around traditional instructional habits and practices, or eliminate the widespread public mistrust of our industry.

Nevertheless, chemical companies and associations must be willing to maintain an ongoing commitment and constancy of purpose through good times and bad. We have to do this because America has an acute need for thousands of scientists, engineers, and technologists. We must get the education process moving in the right direction.

The efforts and concern of everybody are needed to champion new and innovative programs in local school systems, serve on school boards, volunteer in classrooms, create summer jobs and internships in companies for high school students, and adopt schools in one's community and encourage and help them improve science instruction. Perhaps most of all, we must make it clear that we insist on quality education. We need to communicate to students and teachers what those three Westinghouse winners learned so early—that a career in science means excitement, challenge, and a sense of personal fulfillment so great that they wouldn't want to spend their lives doing anything else.

AP 03-15-91 09:20 AET
Company Exec Says More Engineers, Scientists Needed

DENVER (AP) The United States cannot compete fully in a world market because of a shortage of scientists and engineers, and that deficit is just going to grow, a company executive said here Thursday.

In remarks prepared for a meeting of the American Indian Science and Engineering Society, U S West president Dick McCormick said his company already has run into shortages in those areas.

"By the year 2000, we're going to need 18,000 new Ph.D.s in science and engineering every year," he said. "Our colleges' projected output is 10,000. That shortfall -- and similar shortfalls of bachelors and masters in science and engineering — is a great concern."

He said when his company set up U S West Advanced Technologies recently, "we needed software architects, systems engineers, network and LAN (local area network) specialists."

McCormick said the company ended up getting 23 specialists from overseas. "But while we welcome these international staff members, we worry about the lack of Native Americans and other minorities in the nation's engineering programs," he said.

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CHRISTIAN SCIENCE MONITOR

JUN 18 1991 p. 19

US Can't Afford to Let Science Training Slip

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By John W. McFarland

BUSINESS leaders and scholars have warned for several years of a coming shortage of scientists and the severe impact it will have on the economy of the United States. But little change in education has resulted from these warnings.

This spring, President Bush announced his America 2000 program with the goal of improving America's elementary and secondary schools. And in mid-May, $75 million was awarded to 10 states to develop math and science programs for students from kindergarten through college.

Perhaps these efforts will be a step toward reversing the tide of science illiteracy in the US. They will, however, be only a step because much more is needed to keep America competitive in the world market.

The outlook for the natural sciences is particularly grim. Of the 23,000 high schools in the US, 7,100 do not offer physics; 4,200 do not offer chemistry; and 1,900 do not offer biology. American students score significantly lower on science achievement tests than do students in Japan and Korea, for example.

The problem becomes more critical by the time students move into higher education. The number of merit scholars choosing careers in science and engineering has decreased. The percent of college students initially choosing science and math is about half that of the 1960s. A high percentage of those who begin college science drop out of the program during the first year. The number of bachelor's degrees has accordingly decreased.

While the numbers and quality decrease, the need for scientists, engineers, and mathematicians is predicted to increase. Industry, academia, and government are expected to employ an increasing number of these professionals over the next 20 years. One-fourth of college science and engineering faculty will reach retirement age by 1995.

All of these problems and more have prompted the National Science Foundation to predict that by the year 2006, the US will have a cumulative shortfall of 675,000 persons with bachelor's degrees in natural science and engineering. Similarly, **24,000 new jobs requiring PhDs in these fields will be created annually – with many of them going to foreign students.**

Falling interest in the natural sciences parallels declining interest in medicine. **The applicant pool for medical schools dropped from about 42,000 in 1974-75 to approximately 26,000 in 1988.** Applicants to dental schools are down by about one-half since the mid-1970s; now about 90 percent of applicants are accepted.

To keep America at the forefront of scientific technology, any education plan must include the following initiatives:

First, students' interest, imagination, and enthusiasm for the world about them must be captured. Project 2061, sponsored by the American Association for the Advancement of Science, is attempting to do that. The emphasis is on deciding what students are interested in and then illustrating how they can learn about it. The initial interest may be simple, but when curiosity and excitement are turned on they will most likely intensify with time.

Second, teachers fascinated by the world about them must work with students to help them understand that world. Good teachers, education's most prized possession, should be rewarded accordingly in order to avoid losing them to more "prestigious" and financially rewarding activities.

Third, the general public must learn what science is all about. Currently, there is little support of good science education because parents and many decisionmakers do not recognize its importance. They must understand the role of science in our economy and society in order to recognize the danger presented by a shortage of trained scientists. Science-aware parents may see as much glamor and importance in science for their children as they now see in such fields as medicine and sports.

Fourth, colleges must make science a requirement. Any study in science should result in an appreciation of how science works, its limitations, and how it may affect, positively and negatively, all inhabitants of the earth.

There should also be a quantitative element, which deals with the collection and analysis of data. The general public should be capable of making decisions on scientific matters, such as environmental cleanup, safety in handling chemicals, what to eat or not eat, and why. The public should also understand how scientists come to their conclusions and the validity of such conclusions.

A high-technology economy demands a high investment in science. If Americans want to maintain their standard of living into the next century, now is the time for a commitment to science education.

■ *John W. McFarland is chair of the Department of Chemistry at DePauw University in Greencastle, Ind.*

Amid 'Shortage,' Young Physicists See Few Jobs

By **MALCOLM W. BROWNE**

EVEN as leading scientists warn that America's educational system is failing to produce scientists fast enough to fill a glaring projected shortage, many young physicists contend that universities are already turning out far more physicists than there are permanent jobs.

If the job market for research physicists does not radically improve soon, they say, growing numbers of gifted young Americans will be turned away from careers in physics, a field deemed by many experts as vital to maintaining America's technological and economic health.

Permanent research jobs for young physicists have virtually dried up, partly because the recession has drastically undercut the resources of universities and commercial research institutions. In addition, physicists in senior faculty and research positions who had been expected to retire in large numbers in recent years have not done so. At the same time, a growing tide of physicists immigrating from the former Soviet Union and eastern Europe has begun to exacerbate the glut of American physicists.

The situation was underscored last month when Dr. Robert Hilborn, chairman of the physics department at Amherst College, disclosed that 813 physicists had applied for a single job on the college's physics faculty. About three-quarters were recent recipients of doctoral degrees, while some 200 were experienced physicists, including about 60 from the former Soviet Union.

Few young physicists are completely out of work, but many are in temporary postdoctoral positions with low salaries, poor prospects of advancement, and no job security. Many are deeply dissatisfied.

Continued on Page C7

Continued From Page C1

Senior physicists, labeled by many younger ones as "the establishment," contend that an advanced degree in physics is an excellent education, even if it leads to no job. Besides, physicists are at the pinnacle of science, they argue, and superbly qualified to take jobs as applied scientists, engineers or even plumbers.

But young physicists say that even in industry there are all too few jobs available because of the recession and changing industrial research goals. Major commercial laboratories that once employed many full-time scientists now prefer postdoctoral students working as temporary employees.

Despite the scarcity of permanent jobs for starting-level physicists, most science analysts believe the nation will face a dangerous shortage of physicists in the next century.

Anger Among Young Physicists

But many young physicists were angered by a prediction last year from the National Science Foundation that the United States would have a shortage of 625,000 scientists in two decades. The prediction, say many young physicists, was wildly inaccurate and self-serving, intended mainly to nudge Congress into providing more financing for the agency.

Although junior physicists have no formal organization, an informal "Young Scientists Network" was recently founded by Dr. Kevin D. Aylesworth, a postdoctoral fellow at the Naval Research Laboratory in Washington. His information exchange now includes several hundred postdoctoral physicists.

"Established senior physicists simply aren't listening to us postdocs," he said in an interview. "They're too busy finding money for their own institutions and projects. Conditions for us are not what they were when establishment scientists were young. The way things look now, I doubt that there ever will be a shortage of scientists anywhere near as severe as the N.S.F. forecast."

A stream of letters published by the professional magazine Physics Today has echoed Dr. Aylesworth's opinion. "I remain extremely skepti-

A few embittered physicists say education in their field is pointless.

cal about the impending Ph.D. shortage that is supposed to occur when large numbers of present faculty members retire," wrote Dr. Robert J. Yaes of Lexington, Ky. Senior faculty members are postponing retirement, he said, and even those who do retire are sometimes not replaced.

'Chilling Stories'

A few young physicists are so embittered by the slack job market that they believe physics education is pointless.

"The only thing clear is that there are fewer jobs for physicists because there is less economic need for physicists," Murray Arnow of Skokie, Ill., wrote in a letter to Physics Today. "The current commitment by the American Physical Society to promote science education is almost folly given the declining demand for physicists."

Dr. Kate Kirby, an atomic physicist with the Harvard-Smithsonian Center for Astrophysics and chairwoman of the American Physical Society's membership committee, said: "We constantly hear chilling stories. We know of gifted postdoctoral physicists who have held temporary postdoc jobs for seven years or so before reaching the lowest rung of the academic tenure track."

Challenge to Gloomy Outlook

This gloomy view is strongly challenged by Dr. Leon M. Lederman, a Nobel laureate in physics and the president of the American Association for the Advancement of Science.

"The opportunities for scientists in general are tremendous," he said. "A physicist may not always find opportunity in his original narrow research specialty, but only 2 or 3 percent of physicists are actually unemployed. The need for scientists to contribute to the defense of the environment is growing, and physicists will also star in the quest for alternative energy sources and many other social needs. There's no question that the nation will need more physicists."

Far from cutting back science education, Dr. Lederman says, the nation must enhance it at every level, and to that end he has organized a group of volunteer scientists who tutor Chicago-area school teachers in the teaching of science.

But Dr. Lederman and other leading scientists acknowledge that many physics research positions in industry have disappeared because of the recession.

Cutbacks at Laboratories

The trend is evident, for example, at A.T.&T. Bell Laboratories, one of the world's preeminent institutions of physics research whose employees have garnered many Nobel Prizes. The company now employs 172 physicists as permanent staff members and 104 postdoctoral fellows. Very few of the latter group stand a chance of getting permanent jobs with the laboratory, says Dr. Arno Penzias, the laboratory's vice president for research, who is a Nobel laureate himself. On the other hand, Dr. Penzias said, the training postdoctoral fellows receive at the laboratory prepares them for a wide range of physics specialties.

Graduates' Employment Status

[illegible]

	[illegible]	[illegible]
1981	67%	81%
[illegible]	[illegible]	[illegible]
1983	68	81
[illegible]	[illegible]	[illegible]
1985	70	86
[illegible]	[illegible]	[illegible]
1987	72	79
[illegible]	[illegible]	[illegible]
1989	73	85
[illegible]	[illegible]	[illegible]

[illegible]

This trend away from pure research has induced some prominent physicists to leave industrial laboratories for academic positions, a shift that has made academic jobs for young physicists even more scarce.

Dr. Charles V. Shank, director of Lawrence Berkeley Laboratory, worked for 20 years at Bell Laboratories, the predecessor of A.T.&T. Bell Laboratories, before deciding to leave. "It's a very competitive world, and A.T.&T. Bell simply felt that it needed research more closely connected to its near-term business interests than was the case in the past," he said.

A would-be scientist who embarks on a career in physics faces more uncertainties than young scientists in other fields, experts agree. A physicist must complete a doctorate and one or two postdoctoral appointments, usually of two years each, before even becoming eligible to look for an academic job. It is a course of study taking roughly the equivalent time to that needed to become a medical doctor, which is generally much better paid. By contrast, a chemist with only a bachelor's or master's degree can usually find a job in the field, although holders of doctoral degrees command higher salaries.

More Physicists Each Year

Suzanne Ellis, educational studies analyst for the American Institute of Physics, said the average postdoctoral fellow in physics draws a salary of about $30,000, and may have to forgo permanent employment for years. Moreover, she said, more physicists enter the system each year. In 1982, for instance, only 912 doctoral degrees in physics were granted in the United States, while in 1989 there were 1,112 and in 1990 there were 1,183.

"The job shortage these days has its roots in the 1980's, when young physicists began preparing for jobs they expected to be vacated by retirements in the early 1990's," Mrs. Ellis said. "Instead, the senior physicists are not retiring."

In 1990, she said, 12 percent of all physicists with recent doctorates seeking positions received no job offer at all, and 50 percent received only one. In 1989, the comparable figures were 7 percent and 45 percent.

In the last three years, some 40 percent of the new United States doctorates in physics went to foreign students, and this has caused some complaints.

Immigration Policy Criticized

Dr. Aylesworth, while not criticizing the presence of foreign physicists in the United States, believes that Congress seriously overestimated the job market for scientists when it passed the Immigration Reform Act of 1989.

Some scientists and engineers are more harshly critical of immigration policies. Merrill W. Buckley, president-elect of the Institute of Electrical and Electronic Engineers, said last month that immigration of foreign engineers should be curbed in times of high unemployment. "We should be as generous as we can, but we have our own self-interest, from a business and professional point of view," he said in a speech before the Information Technology Association of America.

Few senior physicists agree with this point of view. "Without the foreign physicists who came to the United States during this century, American science would have been in a sorry state," said Dr. Robert C. Dynes, professor of physics at the University of California at San Diego.

But many agree that the current crop of young physicists faces some unusual problems. "The generation born in the 1950's was drawn to physics during the heady post-Sputnik era, when Federal money was pouring into the field," said Dr. Robert L. Park of the American Physical Society. "Now, that population bubble from the 1950's is going through the system, just when the job market is worst. The grim truth is that for the next five years the good jobs in physics research will be hard to come by. "They could become a lost generation," Dr. Park said. "Even worse will be the loss to the nation of all that scientific talent."

Although Some Cynics Call Them Elitist, Math And Science Magnet Schools Flourish

The Scientist, May 11, 1992

Two decades after the bold concept of these specialized high schools was hatched, they are demonstrating their worth

By Susan L.J Dickinson

By now, the gruesome statistics have made it clear that primary and secondary science and math education in the United States is in bad shape, with youngsters manifesting what many officials consider an ominous combination of ineptitude and disinterest:

- The nation ranks 14th among developed countries in terms of students' ability to perform advanced algebra.
- Korean schoolchildren solve complex math problems four times faster than do U.S. pupils.
- A survey of college-bound U.S. high school students revealed that a mere 1 percent were planning to major in math or the physical sciences.
- Meanwhile, the National Science Foundation, in a controversial report, has predicted that within two decades the U.S. will be suffering a shortage of more than 600,000 scientists.

RESEARCH AL FRESCO: Biology teacher Marilyn Link, center, books field trips into her North Carolina students' "rigorous" academic agenda.

Such statistics have convinced Massachusetts state senator Arthur E. Chase that—especially in a state known for its high concentration of technology-based industry—something must be done to alter the bleak predictions for the scientific future of the U.S. His response will take shape in September with the opening of the Massachusetts Academy of Mathematics and Science, a state-funded public high school that will be located on the grounds of the Worcester Polytechnic Institute. Chase has designed this magnet school with the help of a wide range

(Continued on Page 4)

Excerpt from Transcript
of
"The Struggle to Close the Science Gap"
Part I
January 4, 1992
Caucus New Jersey, Rutgers University.

Narrator: During the Gulf War, millions of people watched American Technology in action, from laser guided bombs to patriot missiles. But is America's technological strength at risk, and are we facing a science gap at home?

Dr. Vaughn Vandegrift (Montclair State College): There is no doubt in my mind that we will have a shortfall of trained scientists and engineers. The National Science Foundation has projected that by the year 2006 we will have a shortfall of some 400,000 bachelors level scientists and about 275,000 engineers.

Narrator: There are several reasons why the United States faces such a severe shortage, but Dr. Vandegrift says it's simply a matter of math.

Dr. Vandegrift: Over the last decade or so there hasn't been much of a decrease in the percentage of students choosing careers in math and science. There has been a decrease in the absolute number, so this makes for many fewer being trained in math and science.

Narrator: According to Robin Hogan of Merck, the key is to get kids interested in math and science early in their education.

Mr. Robin Hogan (Merck & Co): Unfortunately our research shows that students get turned off about science early in their careers, and by the time they're 9th graders, freshmen in high school, they have the impression that science is not fun, it's not interesting, it's not a career that they want to pursue.

Nadia Vercer (High school freshman): (Science is)...definitely very time consuming, 'cause I have a cousin who is doing chemical engineering. He said it's very hard and it is going to take a lot of work. And, I mean, just hearing that makes me think about it twice, going into the field of science.

Vanessa Bakert (High school junior): You don't hear people who want to be, like, a scientist or a chemist. They want to be, like, a doctor or a lawyer.

Narrator: Why?

Vanessa Bakert: Because it's, like, a more glamorous thing to be. It's not, you know, like nerdy. You don't think of pocket protectors, you think of TV and "LA Law", and not "Back to the Future".

Narrator: For these and other reasons, less people are choosing careers in science and engineering, and, unfortunately, we are all going to pay the price.

Mr. Hogan: The science base of New Jersey is one of its strongest economic bases. The pharmaceutical industries in New Jersey are doing well. They are employing thousands of people, and frankly, if we can't meet our employment needs in the state, we will have to look elsewhere for where we position our manufacturing and our laboratory facilities. It could have a negative impact overall, long term, on New Jersey's economy.

Dr. Vandegrift: The strength of a nation like the United States is based significantly on its technological superiority. And over the last number of years, a number of people have claimed that we have lost, or are losing, that technological superiority. The strong consensus is that if we don't position ourselves with a technologically and scientifically trained work force, that has the economic strength that we have enjoyed in recent memory will be lost in the future.

Narrator: Right now the U.S. ranks last in math test scores and next to last in science. If this continues, the future of our nation is at risk.

Mr. Kennan Smith (Exxon Corporation): If we are to remain technologically competitive, which will affect the bottom line, the gross national product of this nation, we have got to push math and science, because that is where the money will be made.

Narrator: So what can we do? Some corporations like Exxon are fighting back by teaching the teachers.

Mr. Smith: Many of the teachers in the elementary schools are not prepared to teach science education. And, in fact, that's the last subject generally taught in the course of the school day. We are trying to help teachers get more comfortable, more knowledgeable, in teaching science.

Mr. Hogan: Most teachers who have been out of the classroom for 20 years,and they're a lot of them, really should be going back and re-tooling.

Dr. Vandegrift: An important suggestion that has been made is to get students more involved in the discovery process. Emphasize facts less, and the doing of science more.

Mr. Hogan: You learn by doing, you learn by manipulating. And science is not a vocabulary lesson, it's an experience.

Narrator: But it's an experience that fewer and fewer students are having in New Jersey and across the country. Unfortunately, there is no quick fix for this complex educational, social, and economic problem. Any progress in bridging the science gap will not happen overnight, but will take years of re-education, commitment, and both public and private dollars.

APPENDIX 6

Additional comments submitted for the record.

AMERICAN
ENGINEERING
ASSOCIATION

P.O. Box 820473 · Fort Worth, Texas 76180-0473 Tel. Recorder (214) 264-6428

April 4, 1992

Hon. Howard Wolpe, Chairman
Investigations & Oversight Subcommittee
House Science, Space & Technology Committee
House Annex #1
Room 822
Washington, D.C. 20515

Dear Rep. Wolpe:

Thank you for permitting the American Engineering Association the opportunity to offer written testimony. This is a subject of concern to most engineers today. I do not know of a working level engineer who believes the National Science Foundation is a friend of the engineering community.

Attached is my written testimony and a few sheets of pertinent information. I hope you find both of interest and germane to the hearings of April 8. Other supporting information has been sent under separate cover.

Simply the perception of the need to hold hearings by your committee to look into such a prestigious agency as the National Science Foundation should give us cause for concern. The general perception of NSF as an unbiased organization ended for me years ago.

Should you have questions or want more information feel free to write to the address in the letterhead or call me anytime at (316) 529-6440.

Again, thank you for holding these hearings.

Sincerely,

Billy E. Reed, President

TESTIMONY

of

THE AMERICAN ENGINEERING ASSOCIATION

on

PROJECTIONS OF SCIENCE & ENGINEERING PERSONNEL REQUIREMENTS: HOW GOOD ARE THE NUMBERS?

as presented to

SUBCOMMITTEE on INVESTIGATIONS & OVERSIGHT

of the

HOUSE SCIENCE, SPACE & TECHNOLOGY COMMITTEE

April 8, 1992

by

BILLY E. REED, PRESIDENT

INTRODUCTION

The American Engineering Association is a non-profit corporation with membership in virtually every high-tech center in the United States. We were founded in 1979 to improve engineering and related professions in the area of professional issues. We are dedicated to the enhancement of the engineering profession and U.S. engineering capabilities.

AEA is the only engineering association dedicated exclusively to the professional needs and concerns of the U.S. engineering community. Among these concerns is what we have termed Engineering Shortage Propaganda or ESP.

AEA believes this nations engineers are a valuable resource and as such should be nurtured. It is to this end we offer the following testimony.

I am Billy E. Reed, President of the American Engineering Association. I want to thank the Chairman and the Subcommittee for the opportunity to present our views on this very important issue.

I do not claim to be an expert in statical modeling, nor do know much about how the National Science Foundation operates. There are others here who are more qualified in both of these areas than I. There are problems within the National Science Foundation which I believe are both systemic and very harmful to the engineering profession.

Working level engineers consider the National Science Foundation a very anti-engineer organization. Engineers find this appalling considering our tax dollars fund NSF. This attitude, while perhaps not justified across the entire organization, is based on more than just a gut feeling.

For example, in 1983, the American Engineering Association was working to require foreign engineering students to return to their homeland before being granted permanent residence status to remain here to work. Our amendment was to be introduced by the Hon. Sam B. Hall of Texas and during one conversation with his immigration aide I was told "The pressure against this amendment is incredible. Every member of the Fortune 500 as well as the National Science Foundation has been lobbying us to drop the amendment."

After more discussion, I was told Rep. Hall's office had received several calls from people within the NSF who indicated Mr. Erich Bloch, the then Director of NSF, had asked them to call. I have no reason to not believe Mr. Hall's aide.

Typical of the predictions of engineer shortages was perhaps the most widely quoted "source" of recent times, the American Electronics Association survey which gained prominence in 1983. AEA determined there was going to be a shortage of engineers by surveying themselves. This report was embraced and quoted by everyone from members of Congress to the National Science Foundation, to virtually every trade journal and newspaper in the country to "prove" there was going to be a "crisis level" engineering shortage.

Only after several years of quoting their survey and receiving a significant amount of criticism did AEA admit their survey only indicated a "shortage of electronic engineers" and should not have implied a "shortage of all engineers". In early 1986 Pat Hill Hubbard of AEA finally admitted "the electrical engineering shortage no longer exists".

Ms. Hubbard described an article in the AEA publication "Update" which still maintained there was a shortage of engineers as an "unfortunate editorial misrepresentation" and a problem of "semantics".

The May 12, 1986 issue of Electronic Engineering Times carried a story which makes the following statements: "A high-ranking National Science Foundation official (Mr. Nam Suh) told engineering vice presidents here last week that America engineers are overpaid and less productive than their foreign counterparts." The article goes on to state "When pressed later to clarify his remark, Suh said bluntly "Yes, I think American engineers are overpaid."" Mr. Suh was the assistant director for engineering at NSF at the time.

The article continues "In his speech,.....Suh said there is a shortage of engineers, a contention with which few engineering groups concur."...."He told EE Times afterward. "We need to improve the quality of them and the number of them."" I believe the term "them" is very telling of the attitude of not just Mr. Suh, but the NSF. Engineers are not a "them" or a product to be bought, sold or traded. To his credit, Mr. Bloch reportedly refuted both the "overpaid" and "shortage" statements of Suh.