

REACHING THE CRITICAL MASS IN HIGH SCHOOL PHYSICS

The picture that emerges from the inaugural AIP-AAPT survey of high school physics teachers is of a program that touches few students—and a select few at that in terms of gender, race, social class and geographic region.

Michael Neuschatz

In the past decade a new wave of apprehension about public education—especially science education—has come to the fore. A spate of recent studies has heightened the sense of unease by suggesting a lack of improvement in science proficiency among succeeding cohorts of US students and a slippage in international standings in comparative tests of science knowledge.¹ Such widespread alarm over the academic health of our nation is a relatively new development. Until two generations ago the United States was widely regarded as a pioneer in instituting and extending free and universal public education. Education was extolled as a national resource, and a literate populace was regarded by many as critical to the maintenance of political democracy, to the attainment of a society committed to equal opportunity and the reward of merit, to the pursuit of a robust and internationally competitive economy and to the preservation of a strong national defense.

In the "post-Sputnik crisis" of a generation ago, when we were still in the throes of the cold war, intensified concern with the last of these goals led to alarm over the state of public education, especially science education. Because the problem was framed primarily in terms of one issue—maintaining a strong lead in science and

technology to ensure military superiority—the strategies proposed to address the situation could be implemented in a relatively straightforward fashion. The Federal government, working especially through the National Science Foundation, took an unprecedentedly active stance, developing programs whose primary intent was to channel students with special science and mathematics aptitude into science professions. Although some scientists and educators advocated that more attention be paid to general science education, the primary objective of these initiatives was, as one commentator put it, "to develop a cadre of scientists who could assure that the United States would remain militarily and economically competitive."²

The current wave of alarm is different. Rather than focusing on one area of concern, such as national security, attention is diffused across all four of the objectives enumerated above. And since the different objectives address different populations and involve different sets of skills, the most recent furor has also given rise to a welter of independent and often conflicting policy proposals.

Compounding the problem of conflicting goals is a lack of reliable data, which has stymied efforts to develop appropriate strategies to deal with perceived deficiencies, or even to define the contours of the problem. The extreme diversity in the structures of educational systems in different countries has made meaningful cross-national comparisons that much more complex. Even within the United States, wide variation from state to

Michael Neuschatz is a senior research associate in the education and employment statistics division of the American Institute of Physics, in New York. He is project director for AIP's high school physics teacher survey.



Physics classroom and laboratory at Murray Wright High School in Detroit, Michigan. Nationwide, at urban schools with student bodies made up entirely of minority group members, only 12% of the students take physics, substantially less than the 20% figure for all high schools in the nation. **Figure 1**

state and district to district has hampered effective data collection. And inquiries examining in depth the situation in individual disciplines such as physics, as distinct from science in general, have been almost nonexistent.

Recognizing the need for reliable data to inform the discussion and to assess the situation in physics, the American Institute of Physics, in collaboration with the American Association of Physics Teachers and other AIP member societies, undertook in 1986 to conduct the first nationwide survey of secondary school physics teachers. From a carefully prepared list of public, private and parochial schools across the US, we selected a representative sample of almost 3500 schools that offer instruction through the 12th grade. All but a fraction of one percent of the principals at these schools agreed to participate in the study, providing information about their physics programs and the names of some 3300 teachers at their schools with physics assignments that year. (One such teacher is shown at work in figure 1.)

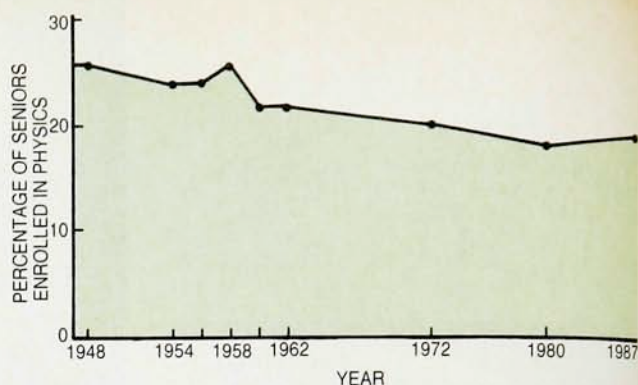
We sent these teachers a detailed, 12-page questionnaire delving into the structure of the physics programs at their schools, their personal and educational backgrounds and their professional and classroom experiences as physics teachers. Although the questionnaires were mailed near the end of the academic year—traditionally the busiest time for teachers—some 2485 teachers, or more than three-quarters of the sample, took the time to respond. The resulting detailed report, *Physics in the High Schools*, was released in November 1988 and is available free from AIP. (See PHYSICS TODAY, November

1988, page 93.) Many respondents appended handwritten comments to the questionnaire describing their personal backgrounds and situations as physics teachers, and a large number registered their appreciation of the fact that they were “finally being asked” about their experiences. (See the box on page 34.)

Physics for the few

In contrast to the impression given by previous research, which stressed the paucity of physics offerings at the secondary school level, the AIP survey shows that physics is widely available to high school students across the nation. Like the previous studies, our study finds that only about two-thirds of all high schools offer physics every year. But about half of the remaining schools regularly offer it in alternate years, and the other half are concentrated among the very smallest schools (especially rural public schools and fundamental religious academies). Hence it turns out that physics is available to 96% of high school students.

Yet overall, only one student in five actually takes introductory physics, a figure that seems to have held roughly stable for the past four decades (see figure 2). (Changes in course definitions and data-gathering methods create formidable obstacles to attempting comparisons with still earlier periods.) Furthermore, barely 1% of students take advanced placement or second-year physics in high school. But even such paltry overall figures do not begin to tell the whole story, for the aggregate numbers conceal sharp and systematic varia-



Physics enrollments in US public high schools since World War II. Figures for 1948, 1960 and 1972 are from ref. 6; 1954, 1956 and 1958, ref. 7; 1962, ref. 8; 1980, ref. 9; 1987, ref. 10. **Figure 2**

tions among schools.

To begin with, we find that the proportion of students taking introductory physics in Catholic high schools and secular private academies far exceeds the proportion in public schools and academies affiliated with fundamentalist religious groups. Among public schools, which have 90% of all enrollment, the data reveal substantial differences by geographic location and racial composition. Thus, schools in the southeastern quadrant of the nation (excluding Texas and Florida) enroll, on average, substantially fewer students in physics than do schools in other sections of the country. The same imbalance holds for schools with large proportions of minority students relative to schools with predominantly white student bodies. And, not surprisingly, we find that schools sending a higher-than-average proportion of graduates on to college have substantially higher enrollments in physics than do schools with fewer college-bound students.

These marked differences between schools are further compounded by differences *within* each school between those students who take physics and those who don't. Not only are the schools with high physics enrollments more likely to have fewer minority and vocational-track students, but within each school, the students in the physics classes are more likely to be white, college bound and male than the student body as a whole.

Although the AIP study did not gather data from individual students, we did ask teachers to estimate the gender composition of their physics classes. Their answers indicate an almost 2:1 ratio of males to females. Corroboration for this, and some indications of other imbalances, emerges from the US Department of Education's recent study *High School and Beyond*, which did conduct interviews with students.³ That study found a slight overrepresentation of white and Asian-American students in physics (with a corresponding underrepresentation of black, Hispanic and Native American students) and a heavy concentration of physics students describing themselves as on the college-preparatory track (with a corresponding scarcity of those describing themselves as on the general or vocational track).

By themselves, our figures and those of the *High School and Beyond* study are not likely to be regarded as especially surprising. It might be argued, for example, that because physics as it has traditionally been taught in high school tends to demand a relatively high level of math skills, the underrepresentation of women, most

minorities and students who do not plan to go on to college simply reflects a lack of such skills among these students. And in fact, these students did score below average on the math achievement test administered in conjunction with the *High School and Beyond* survey—dramatically so in the case of the minorities and the students on the general or vocational track. It also was the case that the overwhelming majority of students taking physics scored above average on the math test.

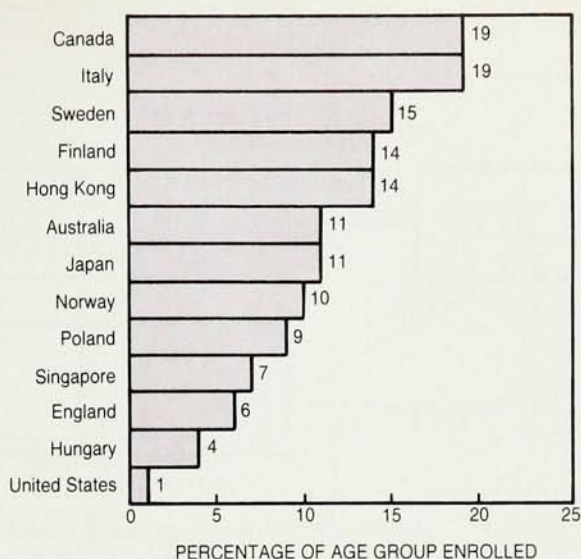
Even if such differences in test scores were able to account fully for the imbalances in physics enrollments, it would only imply that the professional physics community of the future will continue to closely resemble the contours of the physics community of today: a largely white, male bastion in an increasingly female and nonwhite work force—an outcome few would describe as desirable.

But the math test scores alone cannot account for the imbalances in physics enrollments. Even when we focus only on students with above-average scores on the math test, we find that only 11% of the vocational-track students and 17% of the general-track students—compared with 44% of those on the college-prep track—took physics. In fact, college-prep-track students scoring *below average* on the math test took physics in higher proportions than did vocational students who scored above average. A similar finding emerged where gender was concerned. The proportion of males scoring above average on the math test who took physics is roughly double the proportion of females with comparable math scores. Moreover, even these results may understate the underrepresentation of high-ability women, minorities and non-college-bound students in physics classes. Many critics contend that such tests have built-in biases against members of these groups.

Finally, it might be argued that such disparities in enrollments among students with similar math achievement levels exist because members of the underrepresented groups show less interest in math and science or because they do not feel these subjects are relevant to their future career plans. However, the *High School and Beyond* survey inquired about these issues as well, at least as far as math is concerned, and found little or no difference in responses across group lines, regardless of whether one looks at all students or only at those with better-than-average math scores.

Structural barriers

Data from numerous studies in addition to *High School*



International comparison. Proportion of all 18-year-olds taking advanced placement or second-year physics in secondary school. Data from Canada include only English-speaking schools. (From an International Association for the Evaluation of Educational Achievement study.) **Figure 3**

and Beyond indicate that subjects such as chemistry and advanced math exhibit enrollment imbalances similar to the ones in physics. In physics, however, the situation is greatly complicated by the meager overall enrollment figures. The AIP survey of high school teachers suggests that in addition to the broad structural constraints outlined above, there is a further, unique impediment to higher physics enrollments. This impediment seems to arise quite unintentionally as a byproduct of the juxtaposition of two longstanding and widely practiced educational policies.

The first of these policies is that the minimum number of years of science required for high school graduation has traditionally been set low relative to the total number of years of required attendance. The rationale for this has been that the US offers, at least formally, a single, comprehensive system for all students, and has historically retained a high proportion of students until graduation. In contrast, many European countries maintain a formal system of tracking in which students who plan to go on to higher studies are channeled into separate schools with separate curricula; within these schools, specialization is common, and graduation requirements in the subjects of specialization are quite rigorous. In our own country, or at least in the public school sector, which educates 90% of our students, such a formal tracking structure is eschewed. Public high school students on all tracks receive nominally equivalent diplomas covering a broad spectrum of subjects. As a result, formal graduation requirements in any given subject, including math and science, are typically kept low. Although requirements have risen recently, more than 40 states still mandate only one or two years of science to obtain a diploma, while only a handful require three years, and none require as many as four.

The second traditional policy is that physics is typically taught in this country as the last course in the science sequence—biology, chemistry, physics—and is normally taken in the 12th grade. The rationale here is that physics requires relatively advanced math skills and so enrollment is delayed until students can acquire the appropriate background in their math courses. Here too there have been recent proposals to restructure our “layer cake” approach to science and move toward the more integrated model widespread in Europe.⁴ Nevertheless, the AIP survey found that more than 80% of US public high schools still follow the traditional sequence, and four out of five teachers report that the few students who take

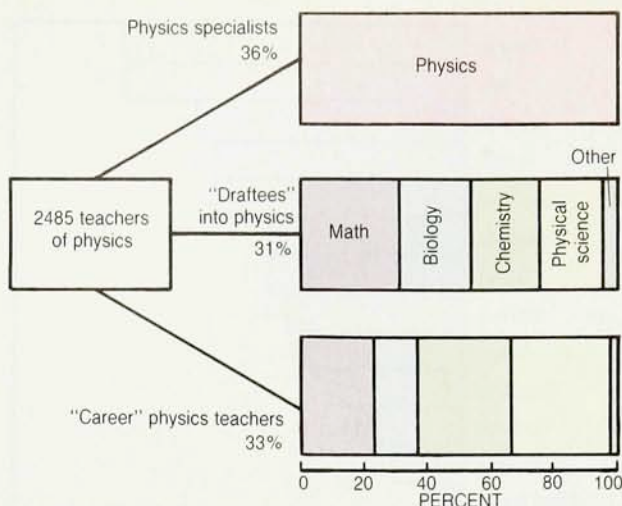
physics normally do so in their senior year.

These two traditions interact to produce a situation in which physics, even more than the other sciences taught in high school, becomes an elective, chosen by the science oriented and the college bound. Students do not have to take physics to graduate, and given its reputation as a “hard” subject, few beyond those who feel they need to take it to prepare for further science course work choose to do so. The upshot is that at least as far as physics is concerned, our students end up being “tracked” by our ostensibly comprehensive and egalitarian educational system even more effectively than their counterparts are in the formally divided structures prevalent in Europe.

In a number of European countries, the proportion of students following the academic track has been rising in recent years, and within that track it is quite common for all students to be required to take at least one year of physics. In many countries all students, regardless of track, are required to take some physics in the lower secondary grades. As a consequence, the overall proportion not just of enrolled students but of all young people exposed to physics turns out to be substantially higher than it is in the US, and the overall percentage of students taking a second year of high school physics far exceeds the number in this country (see figure 3). Yet in spite of the relatively small number of advanced physics students in the US, the achievement tests administered as part of the International Education Association study show that these advanced US students score poorly compared with their counterparts in most of the other countries surveyed.

Lessons in frustration

The picture that emerges is thus one of a physics curriculum that touches few students in high school, and a select few at that in terms of gender, race, social class and geographic region. Even for that select group, the physics program educates unevenly and, in the view of many,



Initial subject specializations of secondary school teachers teaching physics classes. (Data from teachers participating in AIP's survey.) **Figure 4**

unsatisfactorily. Moreover, the findings from the AIP-AAPT teachers survey suggest an important link between quantity and quality. Even putting aside issues of equity, we find evidence that the small proportion of students taking physics has important implications for the structure and quality of the courses offered and for the preparation and experiences of the instructors who teach it:

▷ Low enrollments limit the size of physics programs in the nation's high schools: 75% of schools offer only one or two classes in the subject.

▷ The limited number of classes also limits the scope of the courses from which students can choose. The vast majority of schools offer only the introductory first-year course. Fewer than one in five offer even an honors course, and only one in ten affords the option of taking an advanced placement or second-year class.

▷ The small number of classes means that except in the largest and most advantaged schools, physics by itself cannot support a teacher specialist. Only 28% of physics teachers teach more physics than all other subjects combined.

▷ Even in the best of circumstances this means that a well-trained physics teacher must teach classes in another subject, and in all too many cases it means that teachers from other fields are assigned, often involuntarily, to

teach physics. (See figure 4.)

▷ The small demand for physics teaching creates a tremendous problem of isolation. Eighty percent of the respondents were the only teachers of physics at their schools, and only one in seven of these teachers indicated having frequent contact with physics teachers or even other science teachers at other high schools or at colleges.

▷ The fact that specializing in physics almost always means also teaching other subjects probably dissuades prospective high school teachers from making physics education their focus. Combined with low teacher salaries and ample nonteaching opportunities in the field, it is small wonder that physics is one of the disciplines with the greatest shortage of high school teachers.

▷ Those who do enter physics teaching have to deal with a number of extra frustrations that appear to be exacerbated by the fact that physics is an "orphan" subject at the high school level. Thus 81% of our respondents indicated that they encountered problems in securing adequate funding for equipment and supplies, 76% complained of low student interest in physics as a subject, and 81% indicated problems with lack of sufficient math background among the students in their classes.

Although there is no way to prove it with the data at hand, it seems reasonable to speculate that these difficulties often set in motion a vicious circle. Students, already leery of physics because of its reputation as a hard subject and because of the relatively advanced math background necessary to master it as it is normally taught, may be further dissuaded by the prospect of taking it from poorly prepared and often unenthusiastic teachers, resulting in a further undermining of enrollments.

Complementary goals

Low enrollments have also triggered conflicting reactions outside the classroom, dividing those whose primary emphasis is on wider "physics literacy" from those whose greatest concern is the preparation of professional physicists. Legislators and education policy makers fret about the influence of an unevenly educated populace on our nation's social fabric or the effect of a poorly trained work force on our nation's international economic competitiveness. Many physicists are concerned about the reproduction of their own ranks, given the paucity and, in the view of some, the inadequate preparation of those students who show the most promise and interest in pursuing professional careers in the discipline. All too often such concerns are counterposed in a zero-sum framework, creating a siege mentality in which the allocation of scarce resources to the "opposing" objective is viewed as undermining one's own goal.

In contrast, we would maintain that the findings from our own and other studies give stronger support to the view that broadening physics literacy among all students and preparing future professionals for further work in the field are complementary rather than competing goals. If this view is correct, it is likely that efforts emphasizing one set of goals at the expense of the other will end up worsening the situation in both regards.

The AIP survey found, for example, that even in the

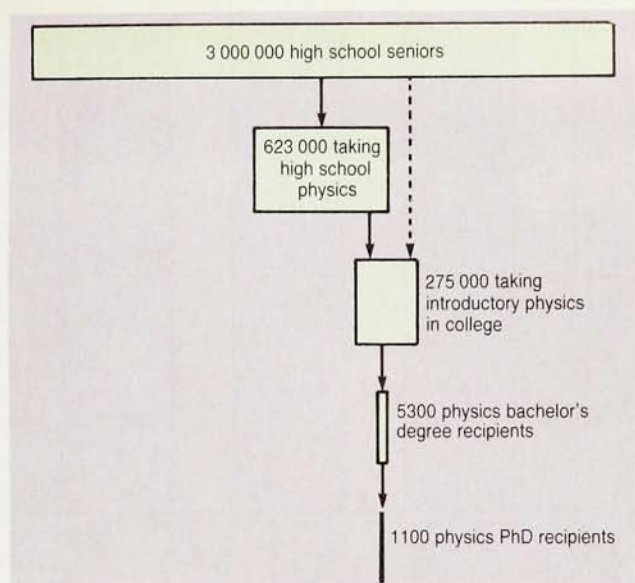
Quotations from Survey Respondents

▷ Thank you for the opportunity to express my feelings and more or less "get things off my chest." If I were to make my opinions public within my community there is a pretty good chance I would be terminated.

▷ We have some very unprepared teachers, who by their very admission... don't even wish to be teaching physics without further training, but must to keep their teaching jobs.

▷ My superintendent hired me last year, knowing I am not certified to teach physics. As a matter of fact, I have never taken a physics course myself.

▷ The public school system is a sick place, and people who haven't been there for a while cannot even begin to imagine the depth of the sickness.



Physics education 'pipeline.' Data are from 1986–87. Figures for total high school senior enrollments and high school physics enrollments come from ref. 10; college course enrollments and physics bachelor's degree recipients, ref. 5. **Figure 5**

public education sector, with its bureaucratic constraints, schools that enroll a high proportion of students in introductory physics appear better able to attract and retain teachers with the strongest background in the subject. Moreover, the larger number of introductory classes permits those teachers to devote themselves more fully to physics rather than dividing their energies among many subjects. However, it is important to note that such benefits of high enrollment are not restricted to the largest schools. Even among smaller schools, we find that those with high enrollments in introductory physics are more likely to include classes in advanced physics in their programs. This phenomenon is especially evident among Catholic schools and secular private academies. While these findings by no means provide definitive confirmation for the notion that broad physics literacy and the education of professional physicists are complementary goals, the findings do supply tantalizing suggestions for further investigation.

The recent IEA study comparing science education in various countries provides additional support for the view that there is a synergistic effect between physics education for the mass of nonscience students and physics education for future scientists. Although a number of other factors undoubtedly come into play here, it is still striking that in all of the other countries studied, the proportion of students—and of all 18-year-olds—enrolled in a second year of physics was markedly higher than it is in the US. Even so, most such students outscored US students on the physics achievement tests.

Impact on the profession

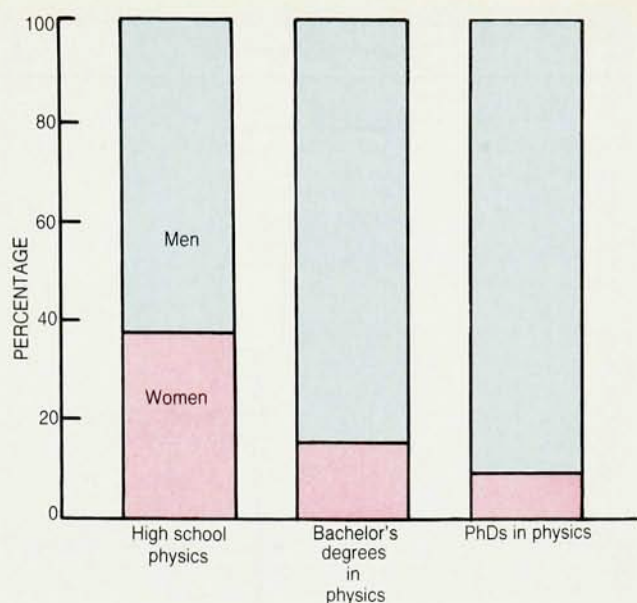
The low enrollments and demographic imbalances that characterize this nation's high school physics programs carry forward and shape the composition of the corps of professional physicists. AIP's most recent annual survey of physics enrollments and degrees shows that the pool of US citizens who receive university physics degrees at both the bachelor's and doctorate level is drawn almost exclusively from that fifth of all students who take physics in high school.⁵ (Few of these future professionals, however, take advanced placement physics at the secondary level.) Figure 5 illustrates how the proportion of students who take physics, already low in high school, shrinks even further at each successive level of specialization in the discipline.

Many of the demographic imbalances that we find in high school physics seem to resonate strongly through each succeeding academic level. For example, it is widely recognized that the number of women and minority students (excluding Asian-Americans) enrolling in physics, disproportionately small in high school, diminishes further by the time students reach the bachelor's degree level, and drops to minuscule proportions at the doctorate level. (See figure 6.) But it is less widely recognized that even for those few who complete a bachelor's degree in physics, the differences in early physics background are quite marked across ethnic and gender lines. While these differences probably matter less as students proceed up the academic ladder, at the undergraduate level they are still likely to have a strong impact on student self-

confidence, on course performance and ultimately on competitive standing in the department and on the possibility of carrying through to higher studies in the field. Those students who enter their college physics programs having already taken college-level advanced placement physics in high school are likely to begin with an important head start, while those who took no physics in high school are undoubtedly starting with a significant disadvantage.

Thus we find that among physics bachelor's degree recipients, far fewer women or non-Asian-American minority students are likely to have taken advanced placement physics in high school than their male, white or Asian-American counterparts; indeed, many more of the students in the former categories are likely to have entered college with no prior physics course work at all. Similarly, the regional differences highlighted in the high school study also show up at the college level: Physics bachelor's degree recipients from the South are far less likely to have taken any secondary-level physics, and graduates from the Northeast are more likely to have taken advanced placement physics in high school. Finally, physics majors at private colleges and universities, which recruit a disproportionate number of their students from private academies and from wealthier suburban public schools, are more likely to have taken AP physics in high school, while a greater proportion of physics majors at public colleges and universities are likely to have taken no physics at all in high school.

What all of this suggests is that the origins of the demographic one-sidedness of the professional physics community reach back through the academic training apparatus at least to high school and get magnified at each successive academic stage. Regardless of their later achievements, most students bear the birthmarks of their scholastic opportunities throughout their academic and professional careers. In fact, there is substantial evidence that the original "sorting process" begins long before high school, in the primary and intermediate grades, where



Male-female ratio for physics students at successive rungs on the academic ladder, 1987. Each year approximately 230 000 women take high school physics, fewer than 1000 receive bachelor's degrees in physics, and fewer than 100 receive PhDs. **Figure 6**

students get their first formal exposure to key analytic skills in mathematics, logic and problem solving. Recognizing that the roots of the demographic imbalances in the professional physics corps extend so deeply into the bedrock of our social structure may help us to understand why those imbalances seem so impervious to corrective measures taken at the level of graduate studies or even beyond, when degree recipients have already entered the labor market.

In a number of ways, the situation just outlined presents opportunities as well as difficulties. The long-term fall in the size of the student population, the decline in the proportion of the labor force made up of white males, the apparent lack of interest of an increasing number of native-born students in pursuing graduate studies in the sciences all provide a practical motivation for efforts to encourage a broader range of students to pursue careers in science—efforts that ideals alone were apparently unable to induce. At an even more general level, the decline in our country's technological standing and the dismal showing of our general student population in international comparisons of math and science knowledge provide an impetus for rethinking course structures that are largely constructed as stepping-stones for students embarked on professional career paths.

But achieving such ambitious goals would require a fundamental restructuring of our educational apparatus, and this is hardly likely to emerge in the near future, even with the best of intentions. As our educational system is currently constituted, initial efforts must take place largely at the state and local levels, and even this requires a concerted push by parents, teachers, students, science educators and scientists for programs that seem most appropriate in their own schools and classrooms. Research like that reported on here can help to inform the process and provide background information, but effective solutions can emerge only from the ranks of those most immediately involved.

Our survey could not have been realized without the cooperation and enthusiasm of the thousands of high school physics teachers and principals who took part, and without the support and encouragement of a number of people at the American Institute of Physics and the American Association of Physics Teachers. Special thanks are due to Beverly Fearn Porter and Maude Covalt-Swearingen for their active role in making this study possible.

References

1. See, for example, the Department of Education's most recent National Assessment of Education Progress, *The Science Report Card*, Educational Testing Service, Princeton, N.J. (1988); and the International Association for the Evaluation of Educational Achievement's second International Science Study, *Science Achievement in Seventeen Countries: A Preliminary Report*, Pergamon, Oxford (1988).
2. E. B. Fiske, *The New York Times Educational Supplement*, 4 January 1987, p. 20.
3. Center for Education Statistics, *High School and Beyond*, US Department of Education, Washington, D.C. (1987).
4. See, for example, B. G. Aldridge, *Essential Changes in Secondary School Science: Scope, Sequence and Coordination*, National Science Teachers Association, Washington, D.C. (1989).
5. S. Ellis, P. Mulvey, *Enrollments and Degrees, 1986-87*, AIP, New York (1987).
6. L. Osterndorf, *Summary of Offerings and Enrollments in Public Secondary Schools, 1972-73*, National Center for Education Statistics, Department of Education, Washington, D.C. (1974).
7. K. E. Brown, E. S. Obourn, *Offerings and Enrollments in Science and Mathematics in Public High Schools, 1958*, Division of Education and Statistics, US Office of Education, Washington, D.C. (1959).
8. *Physics Education, Employment and Financial Support: A Statistical Handbook*, AIP, New York (1964).
9. R. Czujko, D. Bernstein, *Who Takes Science?*, AIP, New York (1989), in press.
10. M. Neuschatz, M. Covalt, *Physics in the High Schools*, AIP, New York (1988).