Physics for All? A Million and Counting!

Fully one-third of recent high-school graduates have taken physics. Much of the increase comes from nontraditional courses geared toward students not headed for careers in science or technology.

Jack Hehn and Michael Neuschatz

Remember when you took physics in high school? You were probably one of a select few. But today, more than a million students are taking high-school physics in the US. Chances are, however, that it's not the same physics course you experienced.

The growth in high-school physics enrollment during the past two decades has been spurred by major curricular changes that draw in more students by moving from a one-size-fits-all approach to more varied course offerings. Enrollment growth has also been promoted by the enthusiasm, energy, and professionalism of good teachers at all levels who are working to improve the system with little expectation of personal gain beyond their deep appreciation of the science and the satisfaction of seeing their students progress.

With enrollment growth and course changes, high-school physics has come a long way. But there is much further to go if science literacy is to be assured for the general public. Continued growth will require new strategies. The pool from which physics students are drawn could be expanded by creating a more engaging introduction to science in earlier school grades. It would also be well to improve the image of physics among parents, teachers, and the general public. But the biggest challenge will be to maintain and improve the quality of the classroom experience for an increasingly diverse group of students while continuing to draw in an ever-larger number of students overall.

Most physicists will not venture to offer expert opinions outside their particular area of research. But, because we've all been through school, almost everyone has strong opinions about education. Schools and colleges resist rapid change. Every year, however, there is a new cohort of students and every year they come with different experiences, different views, different expectations, and different learning strategies. To say that the system is complex is an understatement.

Persistent myths and potential change

In any college or university physics department, you can hear assertions like the following: "There are fewer students taking physics because physics is only for the best and the brightest." "Students are simply not prepared to take a college physics course." "In physics, content is king; we shouldn't be teaching watered-down courses." "Education research can't be done rigorously, so why do it?" "I don't have time to worry about education policy; let politicians and parents run the schools, and let the college of education prepare the teachers." "Education is such a big engine with so much inertia that nothing can be done about it without massive change; and that will never happen."

Despite the obstacles described and often reinforced by such assertions, real change is taking root and more is on the horizon. Six evolving trends increasingly differentiate science and physics education today from what it was in the 1980s.

- More students in more schools and colleges are learning physics.
- The focus is shifting from what is taught to what is actually learned.
- Instructors are increasingly interested in understanding how students learn, and in applying those findings in class.
- There is growing support for a national science-reform effort based on what students should know and be able to do (standards).
- There is increasing attention to the science preparation of future teachers.
- Networks are being developed to promote communication among physics teachers at all levels.

What important issues have we chosen to leave out of this article on physics education? We will not present extensive lists of curriculum-reform projects that have already profoundly influenced instruction, nor will we comment on the transformation brought about by the changes in educational technology. Much has been written about how new technology has affected teaching and learning at all levels; that topic deserves an article on its own.

A growing body of scholarship focuses on ways to improve teaching and facilitate learning. However, large-scale implementations of more-effective practices in science teaching based on such research have been slow to materialize. Ever-more-urgent calls for accountability within the US public education system are answered by the imposition of rather superficial standardized tests. Such testing seems, in fact, to be counterproductive to the kind of in-depth instruction that is most effective in science, engineering, technology, and mathematics.

US colleges do not certify enough teachers who are well prepared and eager to teach science in elementary

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Figure 1. Melba Phillips (1907–2004), a pioneering contributor to physics education, was president of the American Association of Physics Teachers in 1966–67. Although she urged the community to solve problems of science pedagogy, she warned that such problems don't stay solved once and for all. (Courtesy of AIP Emilio Segrè Visual Archives.)

and middle schools, and high-school physics teachers are in short supply. Although science education has been improving, the pace has been uneven. Many Americans still emerge from school with insufficient understanding and appreciation of science.

"Education problems don't stay solved"

Physicists love to solve difficult problems. In years past, a few have brought their prodigious research skills to bear on the improvement of science teaching in the nation's schools. Anthony French cataloged some of these efforts in his November 1981 PHYSICS TODAY article (page 51), noting that "physics education isn't what it was 50 years ago." But, as Melba Phillips (figure 1), president of the American Association of Physics Teachers (AAPT) in 1966–67, liked to caution, however, that "unlike most physics problems, problems in education do not stay solved," today, a small but growing number of physicists are trying to engender a more scholarly dialog about critical issues in education, and they have many insights to offer. This is an important time for our community of scientists and engineers to play a more active and informed role in science education and teacher preparation.

For many years, when we have talked about education within the physics community, we have generally focused our attention from the top down: first on graduate students pursuing a doctorate in a well-defined research area, second on the undergraduate physics majors, and only last on pre-college education and public outreach. Academic departments and faculty members eagerly engage in discussion about how best to improve college-level courses, but they have much less knowledge about or experience in educating children and the public.

From a public policy perspective, however, the word "education" in the US is generally applied to the teaching of students from kindergarten through high school (K–12). In the past two decades, science and science education have once again become the focus of significant ongoing debate. At the same time, many scientists have become more aware of the need to engage in issues of public policy. Those issues involve not only the political dimension of securing funding for science but also the need for citizens, as taxpayers and decision makers, to appreciate science, value its contributions, and articulate their support. The public's knowledge and opinions of science are influenced not only by their own educational experience but also by belief systems formed outside of school.

The physics community received a wake-up call when the annual number of physics bachelor's degrees went through a significant low point in 1999 before beginning to rebound (see figure 2). To address the diminishing numbers of physics majors, the National Task Force on Undergraduate Physics in 2003 published a report entitled *Strategic Programs for Innovations in Undergraduate Physics*, which described the elements that make for a thriving physics department (see the article by Robert Hilborn and Ruth Howes in PHYSICS TODAY, September 2003, page 38). The task force concluded that "[n]o single action, activity, or curricular reform will rescue a struggling physics department. Rather, it takes many elements, interacting over time, to make a department thrive."

High-school physics

In 1987, when the American Institute of Physics (AIP) began conducting its nationwide physics-teacher survey, only one-fifth of high-school graduates had taken a physics course. The closest contact the other 80% had with physics concepts was as part of a chemistry course or a general physical-science course combining physics, chemistry, and sometimes Earth science. Physics itself was regarded as a "tough course," an elective chosen primarily by college-bound seniors who hoped to major in a scientific or technical field.

In the years since then, high-school physics enrollments have grown, from just over 600 000 students per year to about 1 000 000 today. Figure 3 shows that growth as a fraction of all graduating seniors who have taken physics. Only a small part of the increase is due to the growth of the total population of high-school age. Much more of the gain can be attributed to the growing fraction of high-school graduates who enter four-year colleges and universities. But curiously, the percentage of entering college students interested in science careers has been more or less stable. So most of the growth seems to come from college-bound students who are not aiming for scientific or technical careers.

Several developments seem to account for this major shift. In the intervening years, many states have raised their science requirements for high-school graduation. At

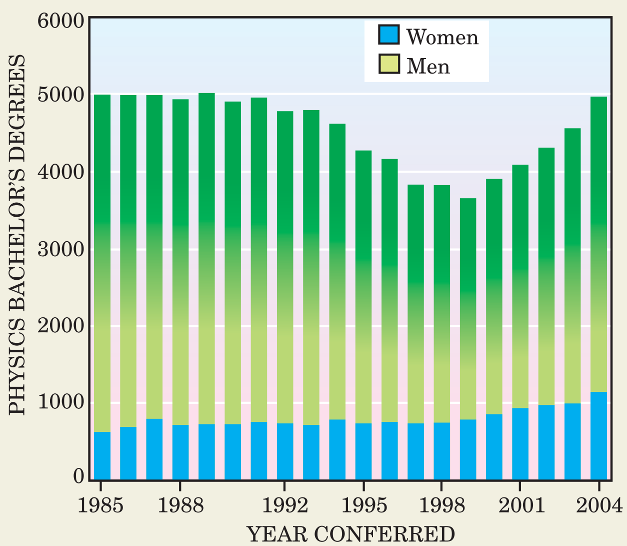


Figure 2. Physics bachelor's degrees awarded annually in the US from 1985 through 2004 dipped to a minimum in 1999 before gradually recovering to the pre-1990 level. (Source: AIP Statistical Research Center.)

the same time, many of the more selective colleges began to raise the bar for applicants, looking favorably on those who showed physics and other college-preparatory classes on their transcripts.

Meanwhile, significant changes were occurring in high-school physics courses, changes that helped to broaden the subject's appeal beyond its traditional student constituency. In AIP's 1987 study, physics teachers classified more than 80% of the physics courses they offered as regular first-year introductory physics, with another 11% being honors introductory courses. Only 4% were designated as advanced-placement or second-year physics. Another 4% were described as conceptual physics, another name for physics for non-science students (see figure 4). By 2005, advanced-placement physics accounted for 11%, and the conceptual-physics fraction had risen to 14%. Indeed, if one lumps nominally "regular" physics courses that have adopted a conceptual-physics approach together with conceptual physics, its fraction almost doubles.

It was particularly the spread of the conceptual approach, aimed explicitly at non-science-oriented students who might not yet have the mathematical skills for a traditional course based on algebra and trigonometry, that spurred high-school physics to grow beyond its traditional confines. That new approach not only treats physics curriculum content in a different way, but also provides an especially fertile environment for new instructional techniques designed to engage students more actively in the learning process.

The expansion of physics enrollment among high-school students not oriented toward science also coincided with a growing participation by girls and minority groups traditionally underrepresented in the sciences. In the two decades during which AIP has been conducting high-school surveys, physics enrollment has significantly changed its complexion from a disproportionately white and Asian male student constituency to one more aligned with the makeup of the US student population as a whole (see figure 5). From 1987 to 1997, more than two-thirds of the increase in physics enrollments was accounted for by the jump in the number of girls taking physics. And from 1997 to 2001, close to half of the absolute enrollment gain was due to increasing minority participation.

Underlying these visible changes is a series of developments that have laid a foundation for expanding the curriculum and addressing the needs of the more diverse student population. Those developments include funding for science-education reform, the formation through science-education research of a theoretical basis for reform, improvements in the education of teachers, and the influence of national science-education policy movements.

Funding for school-science reform

Although public schools are funded primarily by local taxes, school systems depend on federal support for most of the educational experimentation and reform that takes place. Any significant nationwide reform of science and mathematics education must be federally supported to some extent. On the other hand, the principle of local control still dominates American schools. Resistance to the idea of a national curriculum has meant that reform proceeds very unevenly.

Further complicating the picture, the many reform programs supported by federal and private funds have produced thousands of products and processes over many years, with little coordination. The last four decades have seen so many innovations in curricular materials, pedagogic approaches, and educational technology that surveying them here must, perforce, leave out important accomplishments.

The embarrassing launch of the Soviet orbiter *Sputnik* in October 1957 spurred federally funded efforts at science curriculum reform and teacher preparation during the 1960s and 1970s. Experiments with systemic school reform and efforts to deal with

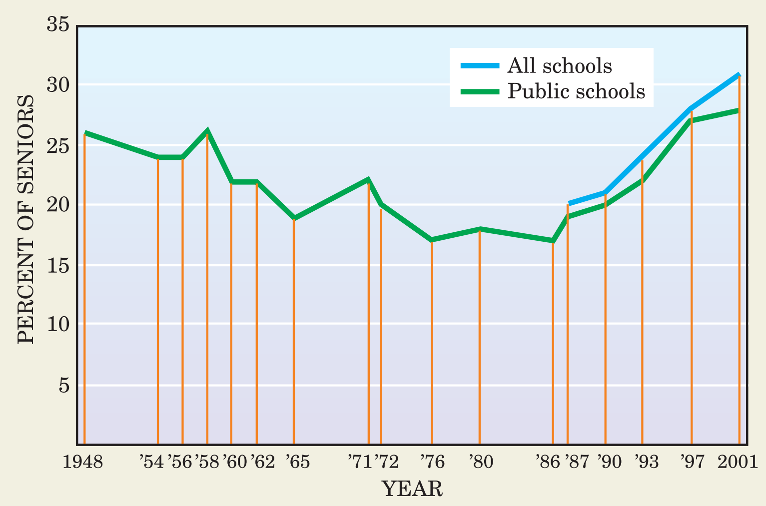
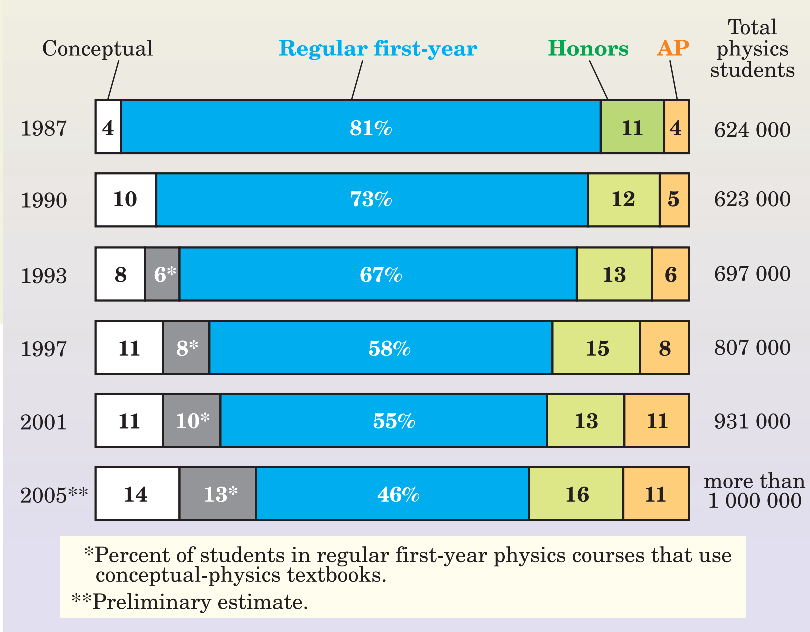


Figure 3. High-school physics enrollment in the US since 1948, measured by the percent of seniors who are taking or have taken a physics course. In 2001, that fraction rose above 30% for the first time. (Adapted from ref. 4.)

Figure 4. Enrollment distribution in different types of high-school physics courses. Regular first-year physics courses are being crowded from both ends of the difficulty scale. Honors and second-year advanced placement (AP) courses now account for 27% of the enrollment. Roughly the same percentage is accounted for jointly by less-mathematical "conceptual physics" courses and nominally regular courses that use conceptual-physics textbooks. (Adapted from. ref. 6.)



poorly prepared science and mathematics teachers dominated much of the funding of the 1980s and early 1990s. But few large-scale or rigorous evaluations ever documented the impact of the work undertaken by those programs. Few published studies attempt to establish a causal relationship between those programmatic reform efforts and student performance outcomes. While funding support was being increased for development and implementation, much less was made available for evaluation and research on the impact of the reforms that had been put in place.

Nowadays, by contrast, there are a growing number of requests for proposals that call for "evidence-based" or "research-based" program design. And they generally require that the proposals provide measurements of student performance.

There is broad agreement on the critical role played by teachers in the reform of science education. Teacher preparation, continuing professional development after certification, and improvement of teacher motivation and morale are clearly important factors influencing student performance. The "teacher enhancement" summer workshops of the 1960s and 1970s are now a distant memory, phased out in response to competing budget priorities and strategies. But many teachers now nearing retirement tell stories of personal transformations that were fostered by the summer workshops. Teachers recall that those summers had enduring effects.

For more than 20 years, AAPT's Physics Teaching Resource Agent program has been providing peer-to-peer professional development for high-school teachers. The program generated a fiercely loyal cadre of activist physics teachers and helped to sustain high-quality teaching as physics enrollments began to increase in the mid-1980s. More recently, NSF and other funding agencies have been supporting science-education reform through the development of instructional materials and the implementation and adaptation of programs to improve the science education of college students, particularly those preparing to be schoolteachers. The programs also address the continuing professional development of practicing teachers.

Current NSF requests for proposals often call for work grounded in "discipline-based" education research—that is, studies specific to teaching and learning a specific subject. NSF also generally mandates that the studies be based on the national science education standards promulgated by the National Academy of Sciences in 1995.[1]

Physics education research

In the past 25 years there has been increasing recognition that reform efforts would benefit greatly from carefully conducted research into the way physics is taught and learned. Groundbreaking studies are laying the foundation for systematic revision of both content and pedagogic practice in introductory and advanced physics courses across the nation (see the article by Edward Redish and Richard Steinberg in PHYSICS TODAY, January 1999, page 24). Physics education research (PER) is now recognized as a field of study in many university physics departments, and faculty members are being tenured and promoted for scholarly work in that field. Physics graduate students are earning degrees with a specialization in PER. Venues are developing for public presentation, debate, and publication on the methods and findings of PER. Physics teachers and college departments are already making changes in instructional practice based on lessons learned in PER.

Physicists doing PER have developed a variety of methods to measure student comprehension of physics concepts before and after instruction. They vary such factors as instructional materials and techniques, learning environments, and the sequencing of events, and then they measure the resulting gain in student comprehension. Thus, PER investigators can hypothesize and test generalizations about how students learn and what strategies are most effective.

Some physics faculty members are still skeptical about how far the applications of PER can be taken. Instructional strategies supported by PER are slow to penetrate into middle-school and high-school physics. Many physics teachers, committed to the practices they have used over many years, are not yet ready to change their wonted methods in light of the direct measures of student learning provided by PER.

National science standards

Since the late 1980s, the school-science reform effort has relied heavily on the development of "standards-based" materials and techniques (see the article by Ramon Lopez and Ted Schultz in PHYSICS TODAY, September 2001, page 44). In 1996, the National Academy of Sciences published its *National Science Education Standards* after almost seven years of community dialog involving thousands of scientists and science educators.[1] *NSES* offered a vision for science education that differed from much of what was being taught, particularly in grades K–8. The primary emphasis

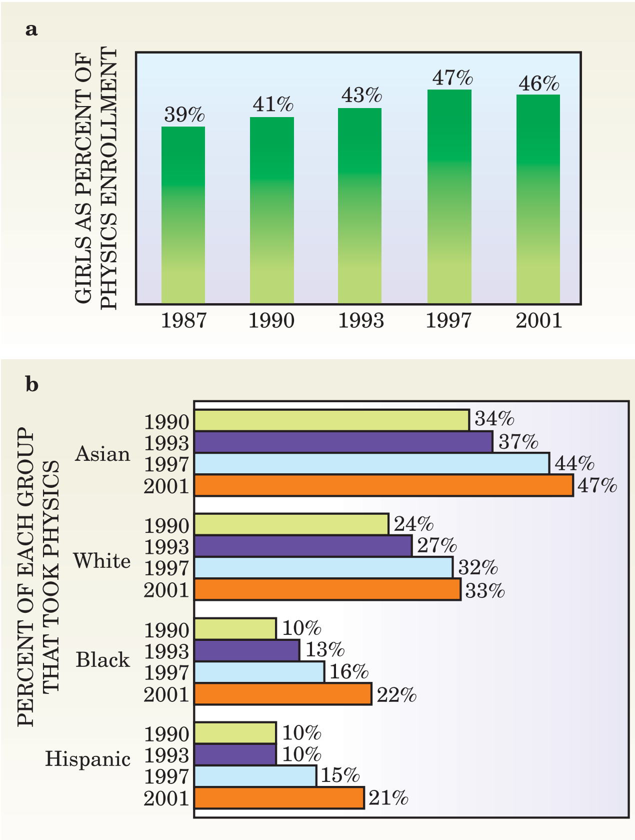


Figure 5. High-school physics enrollment by sex and racial self-identification through 2001. **(a)** Girls as a percentage of total enrollment in high-school physics courses. **(b)** Percent of students in each racial group that took physics in high school. (Adapted from ref. 4.)

was on "science for all," the idea that science education should not be aimed just at the best and the brightest.

Much of the work that led to the standards movement was built on *Science for All Americans*, a 1989 book by James Rutherford and Andrew Ahlgren of the American Association for the Advancement of Science.[2] That book played an important role in Project 2061, a long-term AAAS initiative that has produced reports such as *Benchmarks for Science Literacy*.[3]

Such work led to the formulation of science standards that laid out what a scientifically literate citizen should understand. The standards movement has set out to describe what students should be expected to know, how they might be assessed, how teacher-education programs might be implemented, and how school systems might be organized. The National Academies have continued to prepare and publish a large number of reports in support of *NSES* and related reforms. Much of that effort has centered on engaging post-secondary science and engineering faculties in the preparation of future teachers.

State science standards have now been adopted in 49 states—the lone exception is Iowa. Guidelines direct teachers to provide classroom instruction based on those standards. Many efforts are under way to measure student performance on the various state standards. But the extent to which the standards have actually improved classroom instruction is still unclear. Many physics teachers have reported that the standards have had little impact on their teaching.[4] Others have expressed concern that teachers' views and practical experience were not being sufficiently taken into account when the standards were being translated into actual classroom teaching and assessment of students.

Particular attention has been focused on US Public Law 107-110 of January 2002, the so-called No Child Left Behind Act. The Education Commission of the States describes NCLB as

> a potent blend of new requirements, incentives and resources, and it poses significant challenges for states. The law sets deadlines for states to expand the scope and frequency of student testing, revamp their accountability systems and guarantee that every teacher is qualified in their subject area. NCLB requires states to make demonstrable annual progress in raising the percentage of students proficient in reading and math, and in narrowing the test-score gap between advantaged and disadvantaged students.[5]

NCLB has introduced a welter of new tests, procedures, and concerns. The act has generated both enthusiasm and opposition among teachers. It remains to be seen whether NCLB will have any long-term effect. Moreover, physics teachers are less directly affected by NCLB than are others. Preliminary results from the newest AIP survey of high-school physics teachers indicate that five out of six teachers reported that the effect on them was negligible. Of the remaining sixth, three-fourths said the impact was negative.[6]

Professional development

The slow but steady growth of high-school physics enrollments has proven to be a mixed blessing with regard to teacher preparation. On the one hand, a long-standing shortage of well-qualified high-school physics teachers has affected schools and districts across the US. The shortage was exacerbated by low enrollments. That's because prospective science teachers were often dissuaded from specializing in physics by the realization that they would probably have to teach more classes in other subjects, such as chemistry or mathematics, that had much higher student enrollments.

As a result, more science teachers chose to specialize

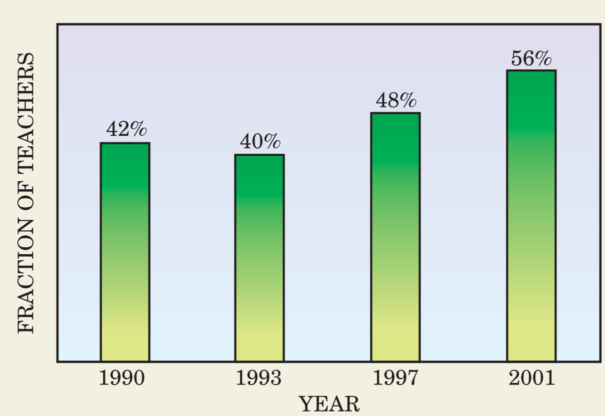


Figure 6. Percent of high-school physics teachers who identify themselves as specializing in the teaching of physics. (Adapted from ref. 6.)

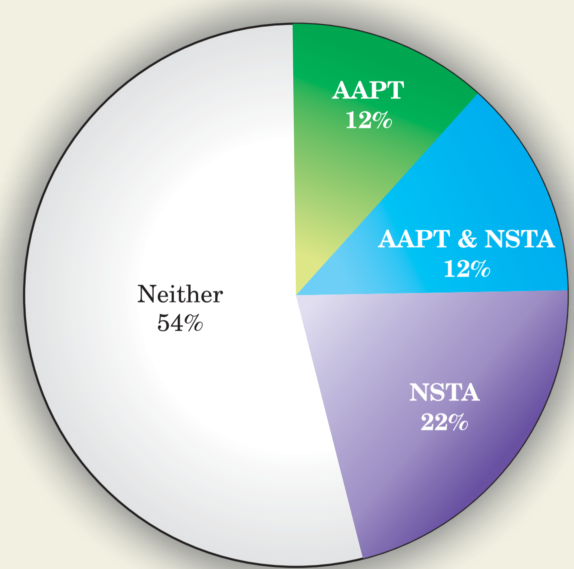


Figure 7. Membership of high-school physics teachers in the American Association of Physics Teachers and the National Science Teachers Association in 2000–01. (Adapted from ref. 4.)

directly in those other, more popular subjects. But many of those teachers then had to teach the one or two physics classes their school offered. In the 1980s, such was the case for three-fourths of the high-school teachers assigned to teach physics. This did not mean, however, that those teachers were uniformly unqualified. In fact, almost all of them had studied some physics in college. According to their responses to the AIP survey, many had several years of experience teaching physics and felt comfortable teaching the basic concepts. As physics enrollments grew during the 1990s, more teachers got the chance to teach more physics, and their comfort with the materials and identification with the field grew. By 2001, more than half the high-school teachers with physics classes described themselves as specialists in the field (see figure 6).[6]

Still, the limited formal physics background of many who teach it in high school underscores the great need for organizations like the AAPT and the National Science Teachers Association (NSTA). They provide a crucial venue for teachers to connect with one another and take advantage of opportunities for continuing education and professional development. Sadly, while the number of teachers with physics classes has grown during the past two decades along with rising enrollments, the fraction that belong to the AAPT or NSTA (see figure 7) has not.

While some of the "crossover" physics teachers were enhancing their proficiency in a subject that was not their original specialty, greater attention was being paid to the preparation of future science teachers. A 2000 National Research Council report entitled *Educating Teachers of Science, Mathematics, and Technology: New Practices for the New Millennium* stressed that the current system for the preparation and ongoing professional development of K–12 science and mathematics teachers "needs rethinking and improvement, and not just on a small scale."[7]

The report offered recommendations for improvement that encouraged partnerships between the K–12 and higher-education communities in providing a seamless spectrum of continuous learning for teachers. It called on university science departments to collaborate with their schools of education in taking primary responsibility for the continuing professional development of science and mathematics teachers. In turn, school districts were urged to take responsibility for ensuring high-quality internships for prospective teachers.

"Before it's too late"

Another report from 2000, this one by the National Commission on Mathematics and Science Teaching for the 21st Century, headed by John Glenn, found not only that US high-school students are "devastatingly far from" the national goal of being first in the world in science and math, but also that "the basic teaching style in too many mathematics and science classes today remains essentially what it was two generations ago."[8]

But on a positive note, the report asserted that a number of factors were now coming together to make 2000 "a particularly opportune time to focus on strengthening mathematics and science education." Those factors included heightened public attention to the problem, a national budget surplus (alas no longer with us), the impending retirement of a significant portion of the teaching force, an accumulation of new education-research results, and rising interest in teaching among college graduates. That convergence of opportunities in 2000 inspired the report's title: "Before It's Too Late."

AAPT, AIP, and the American Physical Society (APS) recognize that professional physics organizations play a critical role as agents of educational change. They facilitate the dissemination of information about the preparation of future physics teachers, and they serve as a public voice for the physics community. In 1999 a statement in support of increased attention to the science preparation of future teachers was passed by the AIP's governing board and later endorsed by seven of the institute's member societies. In April 2003, the senior leadership of AIP, AAPT, and APS asked all US university and college physics-department heads to endorse the statement. Thus far, more than 275 physics departments have done so.[9]

Recognizing the importance of teacher preparation led APS, AAPT, and AIP to join in undertaking a large and multifaceted project called the Physics Teacher Education Coalition—PhysTEC for short. The goal is a national coalition of colleges and universities dedicated to improving the science preparation of future K–12 teachers. This coalition, over time, will encourage education research and promulgate the results in publication and talks. PhysTEC will seek to demonstrate that successful instructional programs in physics departments can indeed play an important role in preparing future teachers.[10]

To start building the coalition, PhysTEC will work to formulate and implement specific programs at a small number of colleges and universities designated as Primary Program Institutions (PPI). The principal goal of the PPI programs is to promote the education of more and better-prepared science teachers committed to inquiry-based, hands-on teaching. That style of teaching, based on the results of PER, encourages students to formulate questions and answer them from personal observation and experimentation.

PhysTEC's goals are fostered by a high degree of collaboration between physics and education departments, creation of teacher-in-residence demonstration programs, mentoring programs for new physics teachers, and dissemination of information about effective teaching practices. PhysTEC envisions a growing scholarly process for documenting the accomplishments of physics departments with respect to teacher education.

Why should you care?

Teachers familiar with the new approaches and methods that come out of physics-education research will be better positioned to meet the next big challenge—pushing high-school physics beyond the comfortable confines of teaching the most academically successful students bound for four-year colleges and universities. The goal is to make physics accessible to the half of all high-school students who are going either directly into the job market or into vocational training for technically oriented careers.

Even students who will not use physics in their future jobs could benefit greatly from a better understanding of the increasingly technical world they live in and from a better sense of how science approaches and answers questions about the world around us. Who will make future decisions about science? The general public must have a reasonable understanding of science if it is to make intelligent decisions about its support and use.

Physicists should care about the education of those who will not become a member of the science or engineering workforce because it is in our own best interest. It's the most effective tool at our disposal for improving the public perception of science and fostering a citizenry that will value science as an essential contributor to their future well-being. Just imagine a cocktail party some time in the future, at which you can say "I'm a physicist" without stopping the conversation or generating horror stories about the physics course your interlocutor had to suffer through. Improving science education for all children is our best hope.

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