feature article

Preparing high-school physics teachers

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By taking on a significant part of the education of high-school physics teachers, physics departments in the US can inspire their students and help ensure a scientifically educated population.

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High-school teachers are one of the most important factors in developing the science and technology workforce of the future. Institutions of higher learning in the US will need to dramatically increase the number of high-school physics teachers they educate if every high-school student who wants to take a physics course is to have access to a highly qualified teacher. The responsibility for that teacher preparation cannot be left solely to education departments or schools of education; we physicists must work with our colleagues in education to address the significant shortage of qualified physics teachers.

Many of the more than 23 000 US high-school physics teachers are not adequately prepared to teach the subject. Only one-third of them, for example, majored in physics or physics education. Poor teacher preparation denies students access to a quality education in the physical sciences. Moreover, students without access to a good high-school physics course are often unprepared for introductory college physics. Physics once attracted the best undergraduates, but now other options seem more attractive. Quantitative indicators are down too. Physics majors now represent only about 1.4% of all science and math undergraduates; 40 years ago the number was 4%.

To improve physics teacher education, the American Physical Society (APS), the American Institute of Physics (AIP), and the American Association of Physics Teachers (AAPT) jointly created the Physics Teacher Education Coalition (http://www.phystec.org) in 1999. Funded primarily by NSF and the APS 21st Century Campaign, PhysTEC has been working closely with about a dozen colleges and universities—and more broadly with a larger coalition of institutions—to identify and disseminate effective practices and innovative methods and to advocate for an enhanced role of physics departments in the education of future teachers.

The number of highly qualified teachers educated at PhysTEC institutions has substantially increased over the past eight years. From our experience in PhysTEC and from visits to successful programs around the country, we are excited to report a number of ideas for helping physics departments to improve the education of future teachers. We include examples and offer suggestions for direct action.

National need

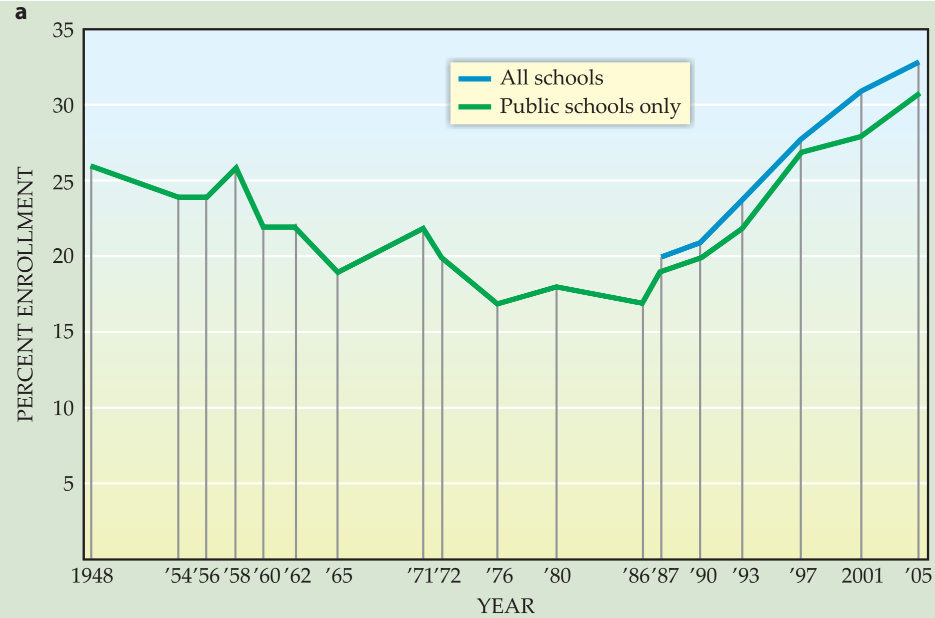
The US has approximately 20 000 public and private high schools. In the 2004–05 academic year, about 1.1 million high-school students took a physics course. As indicated in figure 1a, that's about one-third of high-school students—a dramatic increase from two decades ago.[1] To educate those students, schools hire about 1200 new physics teachers each year; approximately three-fourths of them teach mathematics and other science courses in addition to physics. Only a third of the new hires have a degree in physics or physics education (see figure 1b). Many of the remaining 800 new teachers lack formal training in how to teach physics concepts and are often deficient in physics knowledge. The American Association for Employment in Education reports that with the exception of special-education instruction, physics teacher positions are the most difficult to fill in high schools.[2]

Not all the news is bad, however. The number of physics degrees granted has been increasing since 1999 and reached just over 5700 in 2007. As graduating physics majors increase, the number of teachers is also likely to increase. Still, even if the current rate of increase in physics majors continues, the US will, for the foreseeable future, be woefully short of well-qualified teachers.

Other factors contribute to the growing need for physics teachers. The breadth of high-school physics course offerings is increasing; nowadays more than one-fourth of physics students take honors or other advanced physics courses. Many states have increased their science requirements for graduation. As a result, more teachers are required, especially for teaching the science subjects that seniors take in their final year—and those courses often include physics. College admission offices indicate that students who intend to enter highly selective colleges and universities are taking more science courses to increase their competitiveness. As more students take more physics courses, teachers without full teaching loads can take on additional sections, but it is clear that the demand is continuing to rise beyond the nation's already inadequate supply. Some physics faculty may think the mismatch between supply and demand is not their problem or that high-school teacher education should be left entirely to schools of education. Those physicists are jeopardizing their sources of future majors, and they run the risk that inadequately prepared teachers will alienate potential physics students for years to come.

Program elements

Successful teacher education programs span a continuum of efforts—from student recruitment to postgraduation mentoring of those who eventually enter the classroom. Teachers,



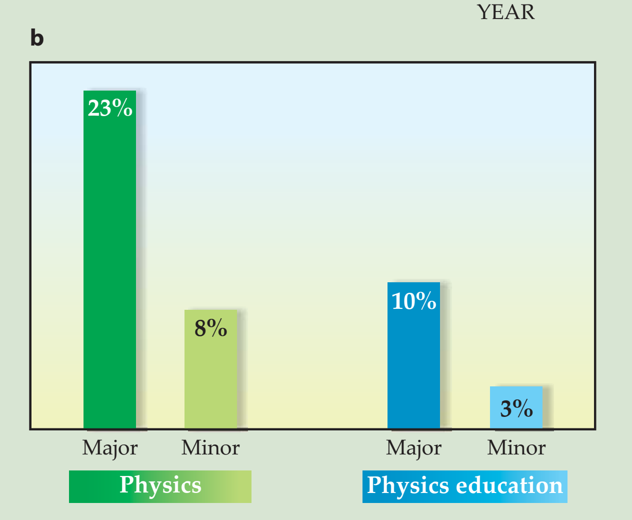


Figure 1. Snapshots of high-school physics. **(a)** High-school physics enrollment has risen dramatically over the past two decades. The graph shows the percentage of high-school seniors who had taken physics or who were taking it in the indicated years. **(b)** In the 2004–05 academic year, some 33% of physics teachers had a major in physics or physics education and another 11% had a minor. In fact, the preparation of teachers has remained about the same for at least a decade. (Adapted from ref. 1.)

like other professionals, are not produced in a single act or even a single semester; rather, they develop and must be supported during that process. The university is most engaged while the future teachers are earning their degrees and preparing for certification. The most effective teacher education programs, however, continue to work with teachers both as they begin their careers and as they mature. That longer-term engagement connects faculty with the reality of their students’ lives, provides feedback to the program, and builds important links to schools.

Faculty who improve or develop teacher education programs should assess future teachers’ content knowledge and pedagogical effectiveness, though admittedly gathering meaningful data in those areas is not easy. Content preparation should include at least a major or minor in physics or an equivalent field like astronomy. Pedagogical effectiveness ultimately determines how well a teacher’s students learn physics. Although it is more difficult to gather data directly from high-school students, student progress data can help teacher and education programs alike. The use of an evaluation instrument—we suggest concept exams like the Force Concept Inventory or the Conceptual Survey of Electricity and Magnetism as a good starting point—helps a teacher understand the value of the curricular or pedagogical ideas embedded in the instrument.[3] In addition, those who work with teachers to gather student progress data get an inside look into the challenges teachers face.

One important aspect of faculty advising is to help college students appreciate their potential as teachers. Often, students don’t realize they would enjoy teaching until they are given the opportunity to try it out. Faculty can help bring students into a teacher education program by providing interactive introductory courses; as a bonus, such courses often increase majors in general. In addition, faculty can offer early teaching experiences that give students low-commitment opportunities to test the waters.

The key to attracting and retaining students in a teacher education program is personal interaction. A recent AIP study showed that almost half of the physics bachelors who became teachers received encouragement from faculty to pursue teaching.[4] Professors often forget that not all students are clones of themselves and that students make career decisions based on widely varying factors. Many of those who became teachers indicated in the survey that “making a difference” had been an important consideration for both how they chose their major and how they planned to apply it once they graduated. Never underestimate the impact that occurs when a student hears a professor say, “I think you would make a good teacher.”

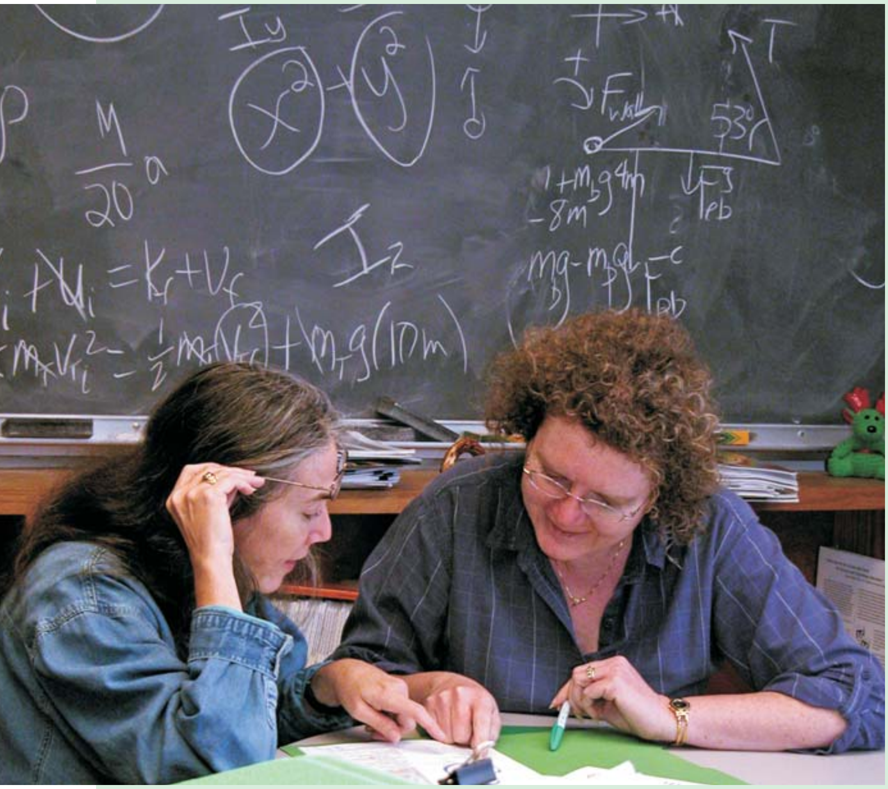
The University of Arkansas has an exemplary program that incorporates many of the features just discussed; for details, see box 1. The result has been a dramatic increase in the number of physics teachers graduating from the university; those graduates are now the main source of high-school physics teachers for the region. The university has also increased the average number of graduating majors from less than 3 per year to about 20.

Specific steps you can take at your institution include the following:

▶ Talk to your students. Find out what motivates them and identify and encourage the ones who seem likely to become teachers. Give individual attention to future teachers and monitor their progress.

Box 1. University of Arkansas PhysTEC director Gay Stewart

The University of Arkansas excels at recruiting and advising physics teachers. The evidence is clear—in the 10 years prior to 2001, when the Physics Teacher Education Coalition project began at Arkansas, only one physics teacher graduated from the university. In the past three years, 20 teachers have graduated, and there is no sign of that number diminishing. At the heart of the Arkansas program is physics professor Gay Stewart, pictured at right in the photograph with one of her students. She used research-tested materials in redesigning the introductory physics sequence to emphasize interactive engagement, initiated a learning assistants program similar to those described in the main text and in box 2, paid individualized attention to students through advising, and helped build in the department a supportive social atmosphere that continues today. Stewart sums up her approach to teacher recruitment this way:



KEN VICKERS

> University of Arkansas' philosophy has been that you never know who is going to be a future teacher, so you should treat all students as if they might be, modeling good pedagogy in introductory physics classes. This has the beautiful side effect that if all students experience an intro class taught the way we would like future teachers to teach, you end up with more MAJORS! Further, the new teachers you have sent out start sending you new, well-prepared, prospective majors.[10]

▶ Make sure that a clear track is available for physics students who want to pursue teacher certification, and understand how it fits in with students' schedules.

▶ Hold an open house, with refreshments, to advertise the teacher education program, and make sure that physics faculty inform their classes about the program.

▶ Adopt interactive teaching methods in your introductory courses, and provide talented students an opportunity to participate as peer teachers or mentors.

Becoming a teacher

The earlier a student can begin practicing the craft of teaching, the better. Most first-year college students do not have well-formed career plans, and those who think they do may change them many times before they graduate. A well-designed early teaching experience can give freshmen or sophomores a taste of the rewards and challenges of teaching. They may be surprised at how much fun they have and how much they learn. But the challenges are not to be underestimated. As one respected study states, "most prospective teachers . . . rarely witness the extraordinary efforts teachers must undertake to educate themselves in their subject-matter. . . . Experiences that allow experienced teachers to share the full picture of teaching with novices make these 'hidden acts' of teaching more visible to prospective teachers."[5]

An innovative program that engages students in teaching is already in place at many PhysTEC sites: the learning assistants program. As described in box 2, LAs act as undergraduate teaching assistants. They receive explicit instruction on how to help students learn effectively and why certain educational methods are better than others. LAs experience teaching firsthand, and evidence suggests that their students learn better.[6]

Teacher education cannot end with a handshake at graduation. There exists today a broad consensus among those working in education that isolation and lack of support are major causes of new-teacher attrition. Stronger induction and mentoring programs are needed to help beginning teachers succeed.

A recent study from the California State University's Center for Teacher Quality reports that teachers who stay in the classroom cite making a difference in student's lives, academic self-determination, and strong collegial support as significant influences in their decision to remain.[7] The first two of those factors are related to school structure and hierarchy, but the last—collegial support—can be addressed by teacher education programs and universities that sustain them. Physics teachers, especially, need outside collegial support because only one in five has a physics colleague at the same school. To address that need, PhysTEC institutions have provided mentoring to nearly 70% of their teacher graduates, nearly all of it by highly respected and experienced high-school master teachers, or teachers-in-residence (TIRs). A full 89% of PhysTEC graduates who went into teaching completed three years; nationwide, according to a US Department of Education survey, the number was 78%.[8] Chance Hoellwarth, a physics professor at California Polytechnic State University, San Luis Obispo, remarked to one of us (Hodapp) that TIRs had skills not possessed by faculty: "Our TIRs could watch a high-school teacher or a student teacher and immediately have three or four suggestions on how to improve a presentation so that the kids would understand it better."

Western Michigan University and Ball State University are leaders in the induction and mentoring of physics teachers. Ball State reported that for the eight-year period ending with the 2006–07 academic year, the classroom retention rate for its graduates was 100%. The vast majority of the activities designed to keep recently minted teachers in the classroom were undertaken by university-hired TIRs who visited high-school classrooms, organized meetings on the Ball State campus for local teachers, and sponsored activities with the local AAPT chapter. Even after they returned to their school's classrooms, the TIRs remained engaged with the university and with the local community of physics teachers. A profile of one such master teacher, each of whom has unique qualities and strengths, is found in box 3.

What can you do at your institution? Here are some ideas.

▶ Invite local teachers to a meeting on your campus. Serve refreshments. Among other things, the meeting can serve to build community among physics teachers, connect future teachers in your program with practicing teachers, and offer a forum in which practicing teachers can help improve the program.

▶ Hire a full- or part-time master teacher from a local school district to serve as a mentor for current and future teachers from your program. The master teacher can also act as adjunct faculty to help offset costs.

Collaboration

At most universities and colleges in the US, education schools are responsible for teacher certification. Our experience suggests that physics departments must get involved if the nation is to address its shortage of physics teachers. The key is collaboration—education and physics faculty strategically using their expertise and resources to take on the diverse challenges of educating physics teachers. An effective partnership can significantly magnify the impact of a teacher education program and develop broad support in the institution. At some PhysTEC sites, open antagonism between physics and education faculty members was replaced with a mutually beneficial working relationship when faculty from each discipline demonstrated professional respect for each other.

Collaboration with colleagues in other science departments is also vitally important. Physics departments typically have fewer majors and prepare fewer teachers than departments such as math and biology; they are thus likely to command a smaller share of institutional resources. In addition, many grant programs, such as the National Math and Science Initiative's UTeach Replication and NSF's Robert Noyce Teacher Scholarship Program, aim to produce science and math teachers generally. Multidepartment partnerships can demonstrate potentially broader impacts and thus gain access to more resources than are typically available to a single department.

Among the steps you can take at your own institution are the following:

▶ Work with your colleagues in the education school to streamline requirements placed on students who want to receive teaching certification in physics or science. One specific action would be to have courses on physics teaching methods count toward both a physics degree and teacher certification.

▶ Collaborate with faculty in your education school and other science departments on joint grant proposals to support future science teachers.

▶ Invite education colleagues to speak to your department and participate on search committees.

Box 2. Learning assistants

Physics faculty at several universities, including the University of Colorado at Boulder, have developed an early teaching experience program—the learning assistants (LAs) program. The Colorado program was originally limited to the astronomy and physics departments, but it has now been adopted in the math, chemistry, and biology departments as well. It has greatly improved induction into the university's teacher education program and has increased the learning gains in introductory physics courses. LAs are recruited from the top 20% of their class and receive instruction on pedagogy in a two-credit course that helps them put theory behind practice. The program provides an opportunity for potential teachers to test the waters by working directly with introductory-physics students in recitation sections (see the figure). The LAs help the beginning students understand concepts through verbal probing and guiding questions. A few LAs immediately see that teaching is not for them. Others—about 15% across math and science disciplines—find the experience a steppingstone into a certification track and a rewarding vocation in a scientific field they love. Valerie Otero, the science education professor who co-teaches Colorado's two-credit class, says, "The Learning Assistant experience helps students realize that teaching is a real intellectual challenge, and for many of them, this is exactly what they're looking for."[11]


GABRIEL POPKIN

▶ Become or support a champion who builds and maintains teacher education programs. Departmental support may include relief from teaching courses, travel funds, or consideration of teacher education support activities when making promotion and tenure decisions.

Steps such as those just detailed were successfully implemented at the University of North Carolina at Chapel Hill. In two years the UNC faculty built a science teacher education program from scratch. Physics professor and department chair Laurie McNeil and her colleagues in biology and education worked together to create a compact and focused curriculum now approved by the state education department. The resulting program requires only four education courses, several of which also satisfy college-mandated general education requirements, and 10 weeks of student teaching. The goal is to have students complete a science major with teaching certification in four years. The program has already enrolled its first teachers and will soon be expanded to include the geology and math departments. McNeil describes some of its benefits:

> It is important not to underestimate the public relations value of doing the right thing. Our program has yet to graduate a teacher, and yet it has already brought praise for the physics (and biology) department from the Dean, the Provost, and the Chancellor. It has been cited as an excellent example of "public engagement" in a major report on that subject prepared by our campus in response to a directive from the President of the

Box 3. Teacher-in-residence Drew Isola

Few physics research faculty have the time or the expertise to carry out effective teacher education programs by themselves. The Physics Teacher Education Coalition teacher-in-residence component, like other teacher education efforts, relies on experienced classroom teachers. Drew Isola, a veteran physics teacher from Allegan, Michigan, served as a TIR at Western Michigan University (WMU) from 2005 to 2007, during which time he helped develop, operate, and improve programs in the physics and education departments.

Isola, shown at right teaching at his high school, brought to the university insights from the classroom; an understanding of learning styles, informed by a PhD in physics education; and a desire to broaden his own career. Like many other TIRs, Isola organized recruiting efforts and worked with university faculty and teaching assistants to help them develop techniques to engage introductory-physics students in both the lecture and laboratory portions of their courses. He also worked with WMU's education faculty to infuse science-methods courses with examples from physics.

As a TIR, Isola traveled to high schools, where he mentored teachers. He also organized on-campus networking gatherings that helped WMU develop a relationship with high schools—one that assisted new teachers in finding discipline-based mentors and allowed the university to provide teachers with useful professional development. Alliances between physics departments and high schools are especially valuable to isolated physics teachers, and they can also provide a source of future majors for the department.

CHRIS BURZA

UNC system. There is much to be said for having something other than publications on the theory of big-bang cosmology to cite when asked for examples of the contributions being made by my department to the state of North Carolina. But the real benefits will be in the longer term, when more students who come to our campus have been taught physics by teachers who truly know and love their subject. I'm looking forward to that.[9]

Yes we can

The PhysTEC project began with the idea that systemic change in high-school physics teacher education has to come from within the physics department. At the heart of good programs are departments that endorse teacher education as part of their mission and support faculty who actively pursue that goal. At each PhysTEC institution, a local leader emerged.

PhysTEC institutions, which represent a wide variety of types and sizes of schools, have shown that physics departments can dramatically improve physics teacher education. Figure 2 shows the growing number of high-school physics teachers educated at PhysTEC sites where the goal was to increase the number of highly qualified teachers. (Some sites focused on other issues. For example, Towson University worked on elementary education.) Each site saw significant growth that far exceeded the national average. Even so, only about two to five teachers per year graduate at the PhysTEC sites. Keep in mind, however, that if every college and university graduated just one more teacher each year, the national shortage would be eliminated. The individual attention paid to students was a key factor in helping them along the path toward becoming a teacher.

A program to improve teacher education can be judged a success only if it is maintained. If you are building such a program now, you are probably wrestling with the issue of sustainability. Several PhysTEC sites have established staff positions with internal funds to continue program efforts. Ultimately, the programs must be supported internally as a component of the service that the institution carries out for its community.

Our philosophy is to apply best-practice ideas that fit the institution; after all, a poorly fitting program overlaid onto an existing curriculum will likely be eliminated when funds are tight. But we also believe in challenging people to think more broadly about how to be successful. That philosophy has been applied to programs like the one at Chapel Hill and the UTeach program at the University of Texas at Austin; at both universities, the idea of graduating with a physics degree and teacher certification in four years seemed impossible. It can be done, but only if both education and physics faculty buy into the concept.

PhysTEC is using the organizational strengths of APS, AIP, and AAPT to disseminate ideas from institutions to a larger audience. The project has organized numerous workshops on specific topics and larger gatherings to facilitate the formation of networks. One success story is the learning assistants program developed at Towson University. Science education professor Cody Sandifer attended a PhysTEC-sponsored workshop on the topic and implemented a pilot LA program in the next semester.

If you are interested in learning more about excellent programs, you may consider urging your department to become a member of PTEC (the Physics Teacher Education Coalition, distinguished from PhysTEC by the acronym), a national coalition, initiated by PhysTEC, of more than 115 institutions. For the past four years PTEC has sponsored an annual national conference on physics teacher education—the only event of its type. PTEC has also created an online library of digital materials. The project's homepage, http://www.ptec.org, includes links to documents, data, and current literature related to physics teacher education.

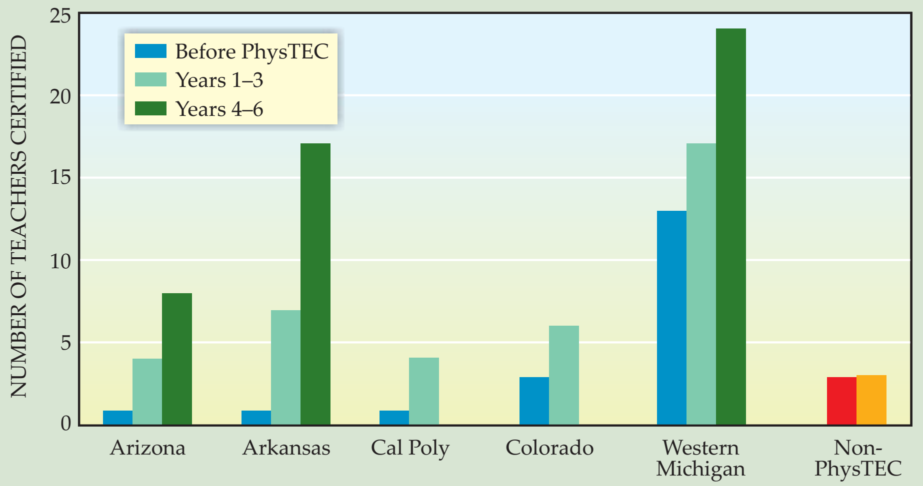


Figure 2. Educating more teachers. The histogram bars for the five named universities illustrate the increasing numbers of teachers educated at PhysTEC institutions. The blue bars show the total numbers of teachers certified in the three years before the university became a PhysTEC site; the lighter green bars show the total number of teachers educated in the first three years that the university was a PhysTEC site; and for those universities that joined the PhysTEC program before 2003, the dark green bars show the number of teachers educated in years 4–6 of participation. The two histogram bars to the right give a baseline determined by averaging over 306 non-PhysTEC institutions in 15 states. The red bar gives the average number of teachers certified in the three-year period 2002–04, and the orange bar gives the average for 2005–07. For additional detail, see http://www.phystec.org/outcomes.

Current activities include a national task force, partially sponsored by PTEC, that is visiting and documenting effective programs throughout the country. The task force plans to publish a report in early 2010 that will describe those programs and synthesize advice for departments that want to improve or develop their teacher education programs. Also planned for 2010 is a collection of peer-reviewed articles on physics teacher education. Those publications will be sent to all physics departments in the US and will be available online.

A charge to physicists

PhysTEC has a viable approach to educating the nation's future high-school teachers. But its long-term aim is not just to understand a solution but to promote a national implementation. In North Carolina, the shortage of physics teachers prompted the president of the state university system, Erskine Bowles, to remark in his 2006 inaugural address, "Think about this: In the past four years, our 15 schools of education at the University of North Carolina turned out a grand total of three physics teachers. Three." Does the effort to address the education of future high-school physics teachers belong in the physics department? APS, AIP, and AAPT agree that it does. We physicists have the most at stake and the greatest potential to effect change. If we do not act, the physics community—and the nation—will lose.

Education is a time-intensive activity, and we are grateful to all who work to educate physics teachers and to all who have helped make PhysTEC a success. In particular, we thank Monica Plisch and Gabe Popkin for their work on the PhysTEC project and their comments on the manuscript. This article is dedicated to the late Fred Stein, who provided much of the original vision for PhysTEC.

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