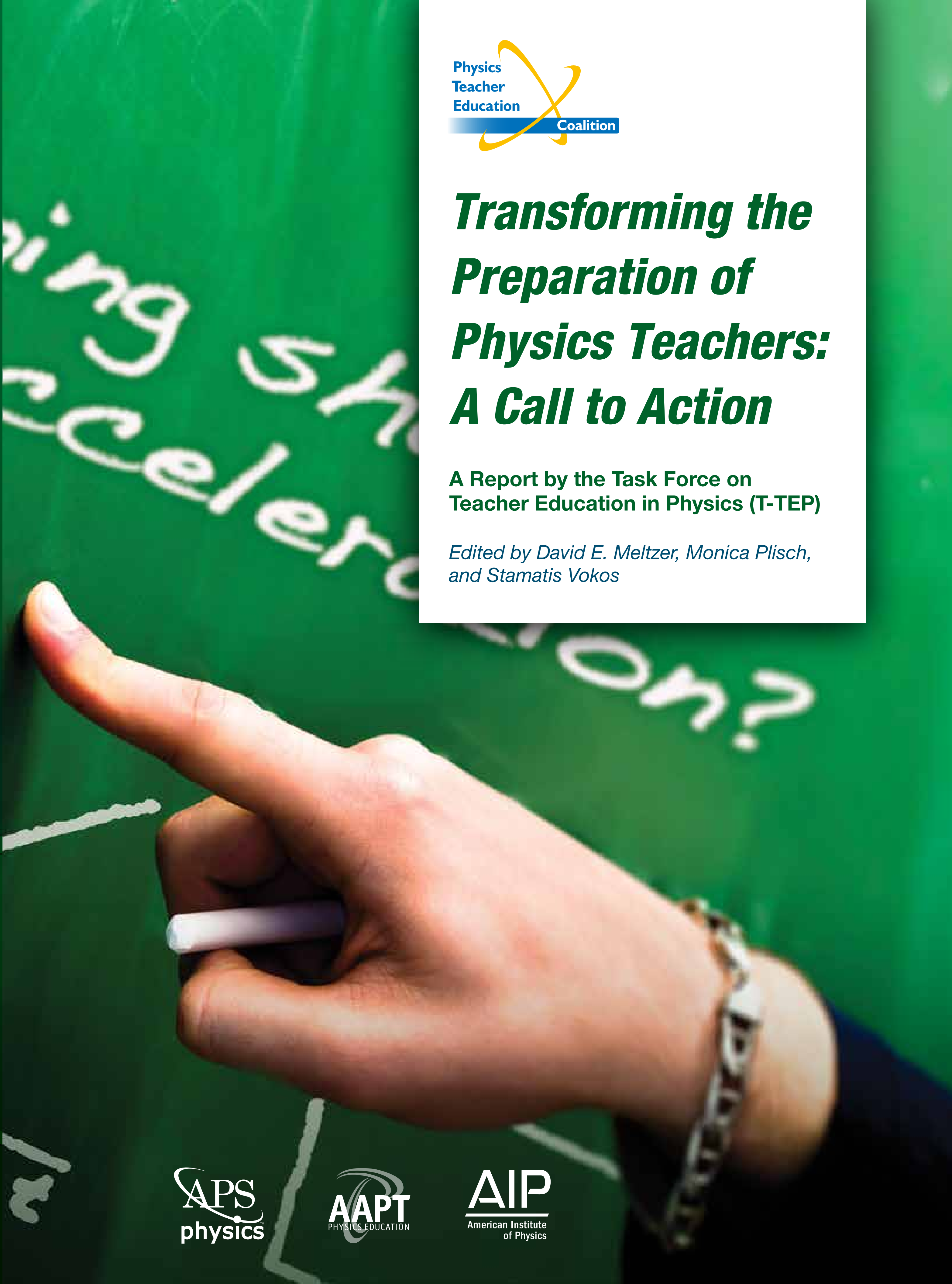
Physics Teacher Education Coalition

Transforming the Preparation of Physics Teachers: A Call to Action

A Report by the Task Force on Teacher Education in Physics (T-TEP)

Edited by David E. Meltzer, Monica Plisch, and Stamatis Vokos



APS physics
AAPT PHYSICS EDUCATION
AIP American Institute of Physics

Meltzer, Plisch, and Vokos
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Additional documents related to this report, including the most recent PDF version, are available at: www.ptec.org/taskforce.

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Preface

T-TEP vision: ***Every U.S. high school student will have the opportunity to learn physics with a qualified teacher***

The Task Force on Teacher Education in Physics (T-TEP) is pleased to present this report as a contribution to the nation's efforts to improve science, technology, engineering, and mathematics (STEM) literacy for all, and to increase the abilities of a STEM-capable workforce as well as the number of students who pursue STEM careers. We believe that a critical factor in helping the nation achieve these important goals is good teaching at the high school level.

Good physics teaching at the high school level is hampered by a severe shortage of well-prepared teachers. This shortage is more pressing in physics than in any other field, and constitutes the primary challenge in providing a high-quality physics education to all students.

To address this challenge, the American Physical Society, the American Association of Physics Teachers, and the American Institute of Physics constituted T-TEP, with members representing all the critical parts of the system under study: physics faculty, education faculty, university administration, high school teachers, and professional organizations. T-TEP found that, except for a handful of isolated models of excellence, the professional preparation of physics teachers is largely inefficient, mostly incoherent, and completely unprepared to deal with the current and future needs of the nation's students. During their training, most U.S. physics teachers took only a small number of physics courses and never developed a deep understanding of the subject, instead devoting much of their time to generic education courses that have limited value to practicing physics teachers. Students typically receive no early experiences in teaching physics before they begin student teaching.

In contrast to this paradigm, research and reports indicate that teachers gain much more value from courses and workshops that expose them to physics-specific pedagogy and intensive study of physics concepts in the context of learning to teach physics—and from actually *teaching* it, with expert mentoring. Such experiences can incorporate recent research in physics education that has yielded valuable knowledge of effective curricula, instructional methods, and assessment techniques. However, these potentially high-value courses and teaching experiences are usually not available at institutions that prepare teachers, and in any case they are almost always overshadowed by the time required for non-subject-specific pedagogical studies. This serious imbalance negatively affects the quality and effectiveness of physics teacher graduates. The fact that most new physics teachers have no exposure to modern knowledge of effective physics pedagogy is a terrible waste of resources and represents a gross inefficiency.

Physics teacher preparation at colleges and universities generally has an "orphan" status, claimed or valued by almost no one, except as a low-priority sideline activity. This is largely due to the relatively small constituencies represented by prospective teachers of physics; the small numbers imply a large relative expense per graduate since economies of scale are lacking. The challenge is magnified since most high school physics teachers teach other subjects as well. This implies a need for physics teachers-in-training to receive preparation in one or more additional subjects such as mathematics, chemistry, or biology, thus straining an already overcrowded curriculum and giving rise to general science methods courses that cannot attend to the many intellectual intricacies of teaching a specific subject. The bottom line is that, with very few exceptions, neither physics departments nor education departments or colleges consider physics teacher preparation to be a significant part of their mission.

Teachers end up in a high school physics classroom through a wide variety of routes. Most often these do not include either a major or minor in physics, or specific training in teaching physics. Even the minority that do have a physics background often obtain only very limited pedagogical preparation in alternative or emergency certification programs, brief "in-service" workshops for practicing teachers, or post-baccalaureate programs with no focus on discipline-specific pedagogy. At the school and district level, administrators are often willing to put underqualified teachers in physics classrooms out of perceived short-term needs, even if the ostensibly short-term "solution" turns into a long-term obstacle to high-quality physics instruction.

To lay out a plan toward national excellence, T-TEP issues recommendations to physics departments, schools of education, university administrators, school systems, state agencies, and the federal government, as well as to foundations and the business community, all of which have indispensable roles to play to help students be prepared to contribute to a STEM-literate society.

Physics is universally recognized as a fundamental and essential STEM discipline. It has been argued that since 21st-century science tackles multidisciplinary problems, school systems should teach science in the interdisciplinary manner in which real science is conducted. We wholeheartedly agree that science should be taught in ways that reflect authentic science and engineering practices, including the use of technology, the incorporation of mathematical modeling, and emphasis on the social and historical contexts in which scientific efforts are situated. That said, we recognize that there are no generic STEM professionals—multidisciplinary teams consist of individuals who have deep grounding in some subject area and are well versed in communicating effectively with colleagues from diverse disciplinary perspectives. Therefore, to prepare a citizenry able to tackle 21st-century multidisciplinary problems, we believe that teachers need a deep understanding both of content within a specific discipline, and of the teaching of that discipline.

This report represents the unanimous voice of T-TEP members. Over a period of four years, T-TEP collected and analyzed data through surveys, site visits, literature reviews, and formal and informal input from many individuals and organizations. T-TEP findings and recommendations were combed through, debated, and vetted by every single task force member, with the ultimate goal of presenting to the nation a unified, authoritative account of the current state of physics teacher education along with specific, actionable items for catalyzing an effective response. We believe this is our best chance to turn around the current tide of mediocrity and to put physics in its well-deserved place in the U.S. education system, as the basis of all science and a major way of knowing the world.

Stamatis Vokos
Chair, Task Force on Teacher Education in Physics
Fall 2012

Acknowledgments

T-TEP gratefully acknowledges the intellectual contributions of numerous individuals. The T-TEP report represents the views of all the T-TEP members. Also, we thank others who shared their expertise with the Task Force and who also provided advice and critical feedback.

Pat Mulvey, Susan White, and Roman Czujko of the American Institute of Physics played invaluable roles in survey development and in data collection and analysis, and assisted us in triangulating data from multiple sources. We are grateful to Sharon Robinson and Yupin Bae of the American Association of Colleges for Teacher Education for sharing data with us. In addition, Pahola Elder of the American Physical Society and Gabriel Popkin, formerly of the APS, put substantial effort into gathering data from state education agencies. Also, we thank the many colleagues who served as site-visit volunteers with members of T-TEP; they are identified in Appendix B.5.

The following individuals provided feedback on early versions of sections of the report: Hunter Close, Assistant Professor of Physics, Texas State University at San Marcos; Charles Coble, SMTI Co-Director, Association of Public and Land-grant Universities; Howard Gobstein, SMTI Co-Director, Association of Public and Land-grant Universities; Frank Kline, Dean and Professor of Education and Movement Studies, Pacific Lutheran University; Ruth Krumhansl, Senior Research Scientist, Education Development Center; Carolyn Landel, Chief Program Officer, Washington STEM; Kimberly Mitchell, (Former) Senior Program Officer, Bill & Melinda Gates Foundation; George (Pinky) Nelson, Former Director, Science, Mathematics, and Technology Education Program & Professor Emeritus of Physics and Astronomy, Western Washington University; Lane Seeley, Associate Professor of Physics, Seattle Pacific University; and Gay Stewart, Professor of Physics, University of Arkansas at Fayetteville.

Robert Frederick provided editorial assistance for an earlier version of the report. Gabriel Popkin, along with Bushraa Khatib and Sara Webb of APS and Ed Lee, formerly of APS, provided invaluable editorial input on the present version of the report.

We thank the gracious hosts at the site visit institutions for reviewing versions of the brief reports from the T-TEP visits that are in Appendix C.

Executive Summary

Introduction

Over the past 20 years, academic, business, and governmental leaders have warned that United States science education needs a dramatic overhaul. These increasingly urgent warnings are prompted in part by a wide array of measures that show science education in the U.S. lags well behind much of the rest of the world, and that in some cases, the gap is growing. The urgency in addressing this need in physics is as intense and pressing as in any other science discipline, if not more so.

Despite federal legislation mandating highly qualified teachers for every classroom, school districts confirm a considerable shortage of physics teachers year after year, greater than any other science discipline. Compounding this problem, the preparation of qualified physics teachers has failed to keep pace with a dramatic increase in the number of high-school students taking physics. Consequently, more students than ever before are taking physics from teachers who are inadequately prepared.

> **"Despite federal legislation mandating highly qualified teachers for every classroom, school districts confirm a considerable shortage of physics teachers year after year, greater than any other science discipline."**

The potential negative consequences of maintaining the status quo are far-reaching, both for physics as a discipline and for the U.S. economy and society as a whole. As international competition for science and engineering talent continues to increase, the United States' ability to recruit foreign-born talent to fuel the nation's technological innovation will become increasingly threatened. Interested in STEM fields but uninspired by physics instruction and unprepared for the challenges physics offers, an ever-smaller fraction of U.S. STEM majors are pursuing physics, and many drop out of STEM completely. Moreover, at a time of unprecedented scientific and technological complexity, many U.S. citizens are unable to participate in STEM-related economic opportunities or informed democratic decision-making.

> **"...the preparation of qualified physics teachers has failed to keep pace with a dramatic increase in the number of high-school students taking physics."**

In response to the shortage of physics teachers in the U.S. and concerns about their effectiveness, the American Physical Society, American Association of Physics Teachers, and American Institute of Physics formed the Task Force on Teacher Education in Physics (T-TEP). T-TEP was charged with documenting the state of physics teacher preparation and with making recommendations for the development of exemplary physics teacher education programs.

Process for Producing this Report

T-TEP engaged in a wide variety of data-gathering activities, including surveying all 758 U.S. physics departments. The survey results provided quantitative teacher-production data and helped T-TEP focus on high-producing institutions (two or more physics teachers per year). T-TEP members followed up with faculty interviews to verify and enrich survey data. T-TEP also conducted site visits to institutions that emerged as local, regional, or national leaders in physics-teacher production and/or had promising and potentially replicable high quality programs. In addition, T-TEP consulted extant research results on teacher education, teacher induction, teacher turnover, and physics education, as well as national reports related to student achievement in science, technology, engineering, and mathematics (STEM); analyzed multiple types of publicly available data to take stock of the current situation in physics teacher preparation in the U.S.; sought advice from teacher education experts, foundation program officers, and policy makers; and collaborated with other organizations with a shared interest in teacher education, including the Association of Public and Land-Grant Universities, the American Association of Colleges of Teacher Education, the Knowles Science Teaching Foundation, and the American Chemical Society.

T-TEP Findings

Except for a few excellent programs, T-TEP found that nationally, physics teacher preparation is inefficient, incoherent, and unprepared to deal with the current and future needs of the nation's students. Most physics teachers have no substantial formal training in either physics or physics teaching. Instead, they develop their skills through on-the-job practice, without expert mentoring, teaching a subject that they never originally intended nor were trained to teach.

T-TEP made eight distinct findings; the first finding consists of two complementary statements.

1. (a) Few physics departments and schools of education are engaged in the professional preparation of physics teachers. (b) Physics teacher education programs produce very few graduates, making it difficult to justify dedicated staff, specialized courses, and other resources.

2. Without exception, all of the most active physics teacher education programs have a champion who is personally committed to physics teacher education. With few notable exceptions, these program leaders have little institutional support.

3. Institutional context appears to be a significant factor in the engagement of physics departments in physics teacher education.

4. Few institutions demonstrate strong collaboration between physics departments and schools of education.

5. Physics teacher education programs do little to develop physics-specific pedagogical expertise of teachers.

6. Few programs provide support, resources, intellectual community, or professional development for new physics teachers.

7. Few institutions offer a coherent program of professional development for in-service teachers, even though most current physics teachers are not adequately prepared to teach physics.

8. Thriving physics teacher education programs exist that can serve as models and resources for other institutions.

   Such programs are characterized by several of the following features, though no institution had all:

   - recognition and support for the champion;
   - targeted recruitment of pre-service physics teachers;
   - active collaboration between physics departments and schools of education;
   - a sequence of courses focused on the learning and teaching of physics;
   - early teaching experiences led by the physics department;
   - individualized advising of teacher candidates by knowledgeable faculty;
   - mentoring by expert physics teachers;
   - a rich intellectual community for graduates.

T-TEP Recommendations

The T-TEP recommendations address the findings identified throughout the four-year investigation and reflect a synthesis of relevant results from the literature on science teacher education and development. The 12 recommendations are grouped into three categories: commitment, quality, and capacity.

Commitment

Physics and education departments, university administrators, professional societies, and funding agencies must make a strong commitment to discipline-specific teacher education and support.

1. Institutions that consider the professional preparation of science, technology, engineering, and mathematics (STEM) teachers an integral part of their mission must take concrete steps to fulfill that mission.

2. Physics departments should recognize that they have a responsibility for the professional preparation of pre-service teachers.

3. Schools of education should recognize that programs to prepare physics teachers must include pedagogical components specific to the preparation of physics teachers; broader "science education" courses are not sufficient for this purpose.

4. Federal and private funding agencies, including the National Science Foundation and the U.S. Department of Education, should develop a coherent vision for discipline-specific teacher professional preparation and development.

5. Professional societies should provide support, intellectual leadership, and a coherent vision for the joint work of disciplinary departments and schools of education in physics teacher preparation.

Quality

All components of physics teacher preparation systems should focus on improving student learning in the pre-college physics classroom. Recommendations 9(a) and 9(b) are intended to be implemented together to ensure that a higher standard for quality of preparation does not increase the length and cost of the program nor decrease the number of teachers who are qualified to teach more than one subject.

6. Teaching in physics courses at all levels should be informed by findings published in the physics education research literature.

7. Physics teacher preparation programs should provide teacher candidates with extensive physics-specific pedagogical training and physics-specific clinical experiences.

8. Physics teacher education programs should work with school systems and state agencies to provide mentoring for early career teachers.

9. (a) States should eliminate the general-science teacher certification and replace it with subject-specific endorsements. (b) Higher education institutions should create pathways that allow prospective teachers to receive more than one endorsement without increasing the length of the degree.

10. National accreditation organizations should revise their criteria to better connect accreditation with evidence of candidates' subject-specific pedagogical knowledge and skill.

11. Physics education researchers should establish a coordinated research agenda to identify and address key questions related to physics teaching quality and effective physics teacher preparation.

Capacity

The United States should take significant steps to alleviate the severe shortage of qualified physics teachers.

12. Physics departments and schools of education should design certification pathways for individuals in various populations to become well-prepared physics teachers: undergraduate students who have not yet chosen a major; undergraduate STEM majors; graduate students in STEM disciplines; STEM teachers who may not yet be prepared to teach physics; and STEM professionals such as engineers, scientists, and laboratory technicians.

A National Proposal: Regional Centers in Physics Education

The T-TEP recommendations address crucial issues at the level of individual institutions and programs. However, an effective and coordinated national strategy in physics teacher education must go beyond the individual implementation of the recommendations listed above. An innovative national program is needed to develop new resources, expertise, and capacity in order to meet current and future national needs. Toward this end, T-TEP recommends establishing regional centers in physics education.

Funded by colleges, universities, private foundations, and federal and state agencies, these centers would be the main regional producers of well-qualified physics teachers and would be a nexus for scholarly work on physics education. In addition to graduating early-career teachers of physics in sufficient numbers to meet regional needs, the centers would improve student learning of physics at the elementary and middle-school levels by helping veteran science teachers at these levels deepen their knowledge and skills. The scholarship conducted at regional centers would include research on teacher preparation, investigation of student learning, development of instruments to assess teacher attributes and impacts, program evaluation, and development of education policy. Finally, such regional centers may serve as models for discipline-based preparation and enhancement of other STEM-discipline teachers.

Chapter 1: Introduction

The need for qualified physics teachers is greater now than at any previous time in U.S. history. While the shortage of physics teachers is not new, and in fact has been a characteristic of U.S. secondary education for over a century, current conditions create a new level of urgency. An acute shortage of new physics teachers, compounded by often inadequate preparation of current teachers to teach their subject effectively, has increasingly detrimental effects on our nation's competitiveness in scientific and technical industries. The shortage also impacts ever more severely our citizens' ability to engage meaningfully with global challenges of unprecedented scientific and technological complexity. Moreover, it has a direct impact on the future of physics as an important intellectual and social endeavor, not to mention the long-term health of college and university physics departments.

> **"The need for qualified physics teachers is greater now than at any previous time in U.S. history."**

Shortage of physics teachers

School districts rank physics as the highest need area among all academic disciplines with regard to teacher shortages.[1] Only 47% of physics classes are taught by a teacher with a degree in the subject, compared with 73% of biology classes and about 80% of humanities classes (see Figure 1).[2] Of the approximately 3,100 teachers who are new to teaching physics each year,[3] only about 1,100 or 35% have a degree in physics or physics education.[4] This appears to be a long-term trend, as only 35% of the 27,000 U.S. high school physics teachers have such degrees, suggesting that most physics teachers have no substantial training in either physics or physics teaching.[5,6]

At the same time, there has been rapid growth in the numbers of high school students taking physics: over the past two decades, that number has doubled to 1.35 million students, with the number of Advanced Placement or second-year physics students increasing more than five-fold to 182,000 (see Figure 2 on page 2). Overall, 37% of high school graduates have taken a physics class.[7] While such growth in the popularity of physics is positive, it adds to the demand for qualified teachers.

Many current science teachers lack the content knowledge and focused pedagogical preparation needed to teach physics effectively. In many states, this fact is hidden by weak standards for certification or endorsement. For example, some states offer an "all sciences" certification that allows a teacher to teach any science discipline, typically with as few as two college courses in the discipline as required preparation. Other states allow a science teacher to add an endorsement in a particular discipline simply by passing a written test. States' compliance with federal legislation (such as *No Child Left Behind*) mandating highly qualified teachers for every classroom has done little to address the need for adequate numbers of well prepared teachers. While many high school physics teachers are excellent educators—with or without physics-specific degrees–overall student performance in physics is subpar, suggesting that many are not.

Mediocrity of physics performance by U.S. students compared to their international peers

In 1995, the last time the U.S. participated in an interna-

1. American Association for Employment in Education, Inc., *2010 Executive Summary: Educator Supply and Demand in the United States* (AAEE, Columbus, OH, 2010).
2. Jason G. Hill and Kerry J. Gruber, *Education and Certification Qualifications of Departmentalized Public High School-Level Teachers of Core Subjects: Evidence from the 2007-08 Schools and Staffing Survey, Statistical Analysis Report* [NCES 2011-317] (National Center For Education Statistics, U.S. Department of Education, Washington, D.C., 2011). Available at: http://nces.ed.gov/pubs2011/2011317.pdf.
3. Annually, the nation hires 1400 teachers who are new to teaching physics and also new to teaching high school students; the remaining 1700 teachers are experienced high school teachers who are new to teaching physics; see: Susan White and Casey Langer Tesfaye, *Turnover Among High School Physics Teachers* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/hsturnover.pdf.
4. Casey Langer Tesfaye and Susan White, *High School Physics Teacher Preparation* (American Institute of Physics, College Park, MD, 2012). Available at: http://www.aip.org/statistics/trends/reports/hsteachprep.pdf.
5. Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, 2010). Available at: http://www.aip.org/statistics/trends/reports/hsteachers.pdf.
6. The more qualified teachers teach a greater number of physics classes, so about 43% of all physics students have a teacher with a degree in physics or physics education. (Source: Private communication from Susan White, American Institute of Physics.) A somewhat different statistic is reported by the U.S. Department of Education National Center for Education Statistics (NCES), which claimed that 51% of physics students are taught by a teacher who has a major in the discipline. However, larger schools were more likely to be selected in the NCES sampling methodology, which probably resulted in over-sampling of physics teachers with a physics degree. See report cited in Footnote 2.
7. Susan White and Casey Langer Tesfaye, *High School Physics Courses & Enrollments: Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010). Available at: http://www.aip.org/statistics/trends/reports/highschool3.pdf.

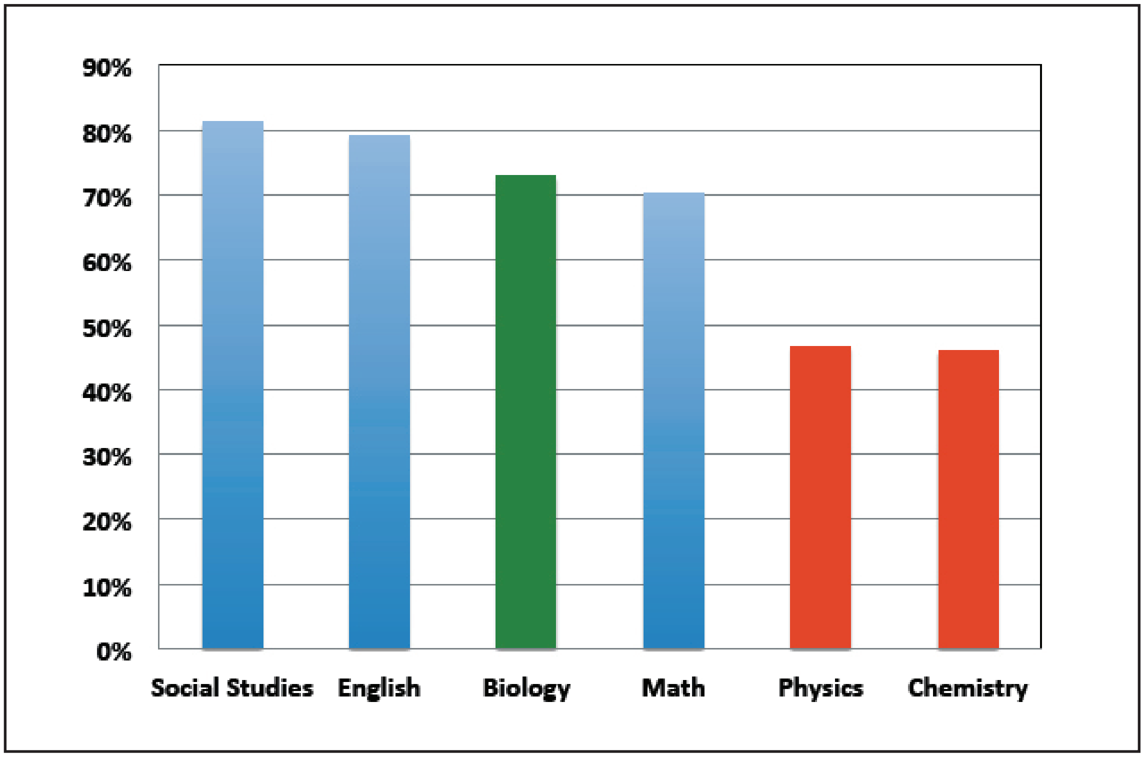

Figure 1. Fraction of high school classes taught by teacher with degree in subject/Source: See Footnote 2

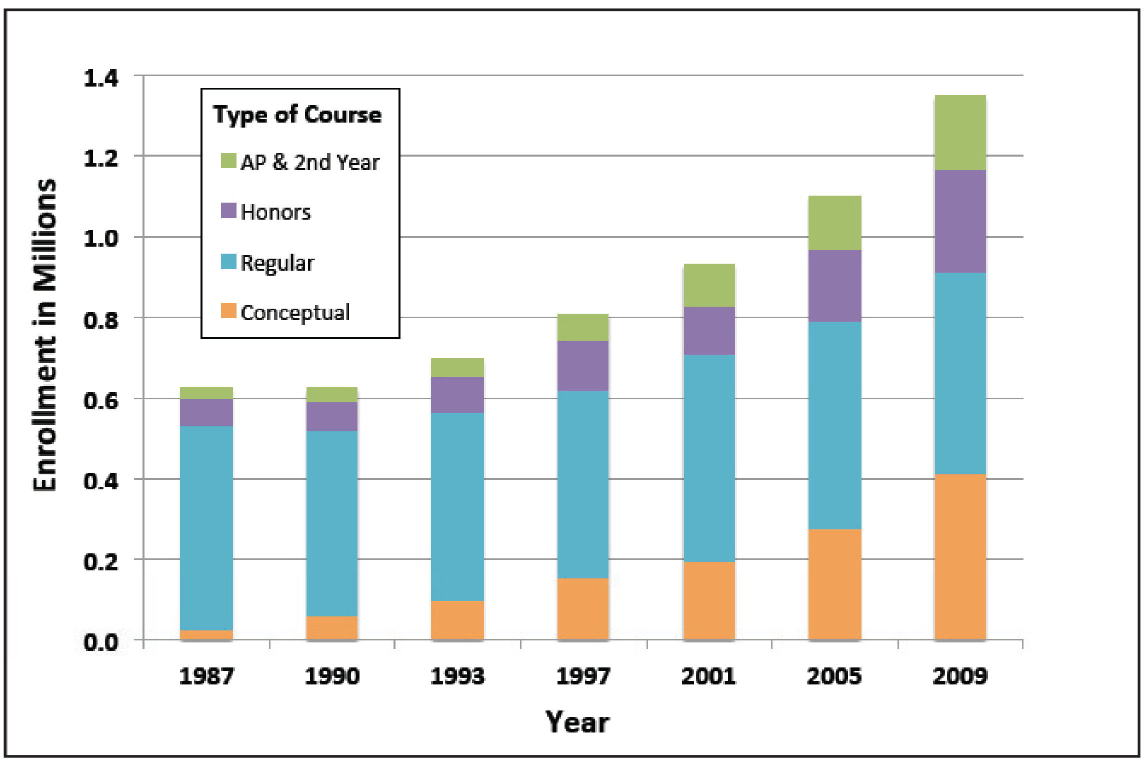

Figure 2. Physics enrollment in U.S. high schools/Source: See Footnote 7

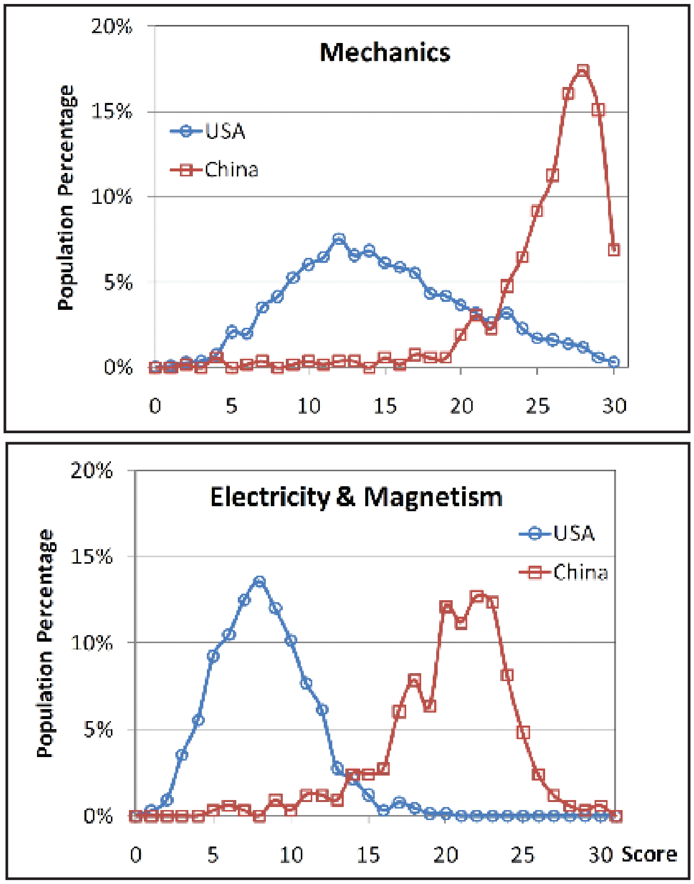

Figure 3. Concept exam scores for entering college students in U.S.A. and China. From L. Bao et. al., "Learning and Scientific Reasoning," *Science* **323**, 586-587 (2009). Reprinted with permission from AAAS.

tional study that tested high school physics proficiency (the Third International Math and Science Study or TIMSS), U.S. students got the lowest score behind 14 other nations.[8] There is little reason to think that U.S. science education has improved much since then. Neither U.S. fourth nor eighth graders showed a measurable change in science achievement in 2007 compared to the 1995 TIMSS results.[9] U.S. mediocrity in precollege physics student performance reflects the substantially more stringent requirements that most other industrialized nations have for physics coursework in grades 6-12 compared to most states in the U.S. Unsurprisingly but alarmingly, a more recent study from 2009 comparing student understanding of basic physics concepts indicated that student performance in the U.S. is about two standard deviations lower than that of their peers in China (see Figure 3).[10]

In yet another international study, the 2009 Programme for International Student Assessment (PISA), the average science literacy score for U.S. 15-year-olds was indistinguishable from the average for Organisation for Economic Co-operation and Development (OECD) nations.[11] This places U.S. students behind 12 OECD nations, including Japan, Korea, Germany, and Canada. Truly, U.S. students have fallen behind their counterparts in many other industrialized nations.

Economic implications of substandard student achievement

Substandard U.S. student achievement in science is coupled to the significant demand for foreign-born science and engineering (S&E) workers to fill positions in what is known as "Knowledge- and Technology-Intensive Industries;" these industries have been a major and growing part of the U.S. economy, and currently represent 40% of the U.S Gross Domestic Product.[12] The current size of the S&E workforce is over 5 million, and several million more workers outside S&E occupations use related knowledge and skills in their jobs.[13] In 2003, it was estimated that about 25% of the entire S&E workforce was foreign-born, as were 40% of doctorate holders in S&E occupations; these percentages are likely higher today given increasing trends over time. Physical sciences, computer/mathematical sciences, and engineering had the highest fractions of foreign-born individuals.[14]

8. (a) Ina V. S. Mullis, Michael O. Martin, Albert E. Beaton, Eugenio J. Gonzalez, Dana L. Kelly, and Teresa A. Smith, *Mathematics and Science Achievement in the Final Year of Secondary School: IEA's Third International Mathematics and Science Study (TIMSS)* [IEA = International Association for the Evaluation of Educational Achievement] (Center for the Study of Testing, Evaluation, and Educational Policy, Boston College, Chestnut Hill, MA, 1998). Available at: http://timss.bc.edu/timss1995i/HiLightC.html. (b) TIMSS International Study Center, *TIMSS Physics Achievement Comparison Study: IEA's Third International Mathematics and Science Study* (TIMSS International Study Center, Boston College, Chestnut Hill, MA, 2000). Available at: http://modeling.asu.edu/Evaluations/TIMSS_NSFphysicsStudy99.pdf.
9. Patrick Gonzales, Trevor Williams, Leslie Jocelyn, Stephen Roey, David Kastberg, and Summer Brenwald, *Highlights From TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context* [NCES 2009–001 Revised] (National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, D.C., 2009). Available at: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2009001.
10. L. Bao et al., "Learning and scientific reasoning," *Science* **323**, 586-587 (2009).
11. OECD, *PISA 2009 Results: What Students Know and Can Do – Student Performance in Reading, Mathematics and Science (Volume I)* (OECD Publishing, Paris, 2010). Available at: http://www.oecd.org/pisa/pisaproducts/48852548.pdf.
12. National Science Board, *Science and Engineering Indicators 2012* [NSB 12-01] (National Science Foundation, Arlington, VA, 2012), pp. 6-1 to 6-74, "Chapter 6: Industry, technology, and the global marketplace." Available at: http://www.nsf.gov/statistics/seind12/c6/c6h.htm.
13. National Science Board, *Science and Engineering Indicators 2012* [NSB 12-01] (National Science Foundation, Arlington, VA, 2012), pp. 3-1 to 3-65, "Chapter 3: Science and engineering labor force." Available at: http://www.nsf.gov/statistics/seind12/c3/c3h.htm.
14. National Science Board, *Science and Engineering Indicators 2010* [NSB 10-01] (National Science Foundation, Arlington, VA, 2010), pp. 3-1 to 3-60, "Chapter 3: Science and engineering labor force." Available at: http://www.nsf.gov/statistics/seind10/c3/c3h.htm.

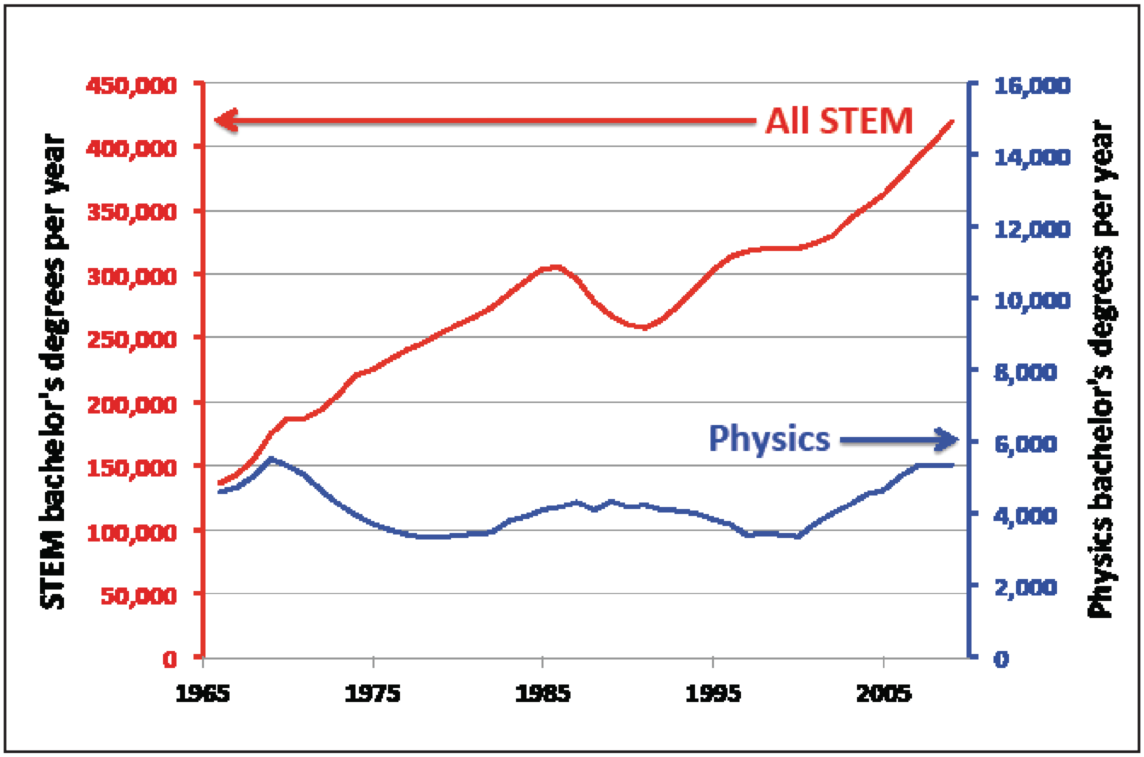

Figure 4. Growth of bachelor's degrees in physics compared to all STEM fields/Source: See Footnote 26

However, dependence on foreign-born S&E workers is not a sustainable strategy over time. A National Science Board task force has warned that "global competition for S&E talent is intensifying, such that the United States may not be able to rely on the international S&E labor market to fill unmet skill needs."[15]

Inadequate and inequitable science education as a threat to democracy

Students with access to a good science education are in a position to benefit from economic opportunities in the Science & Engineering (S&E) sector. The median salary for workers in S&E is more than double that of the overall U.S. workforce, and unemployment rates are lower than in other employment sectors.[16] Yet, access to a good science education is far from equitable. Results from the 2005 National Assessment of Education Progress (NAEP) showed large and persistent science achievement gaps among races and ethnicities at all grade levels: For example, 65% of white students were at or above the basic level in science compared to 19% of black and 30% of Hispanic students.[17] With respect to physics in particular, high poverty schools are less likely to offer physics courses, especially advanced physics.[18] In addition, teachers of physics at such schools are less likely to have a degree in physics or physics education.[19] Since the U.S. population is becoming more diverse by race and ethnicity,[20,21] these issues of unequal access to a good science education and the associated economic opportunities will only become more urgent. Indeed, inadequate science education threatens the very foundation of our democracy as meaningful participation in crucial

15. National Science Board, *The Science and Engineering Workforce: Realizing America's Potential* (National Science Foundation, Washington, D.C., 2003), p. 9. Available at: http://www.nsf.gov/nsb/documents/2003/nsb0369/start.htm.
16. National Science Board, *Science and Engineering Indicators 2012* [NSB 12-01] (National Science Foundation, Arlington, VA, 2012), pp. 3-1 to 3-65, "Chapter 3: Science and engineering labor force." Available at: http://www.nsf.gov/statistics/seind12/c3/c3h.htm#s3.
17. W. Grigg, M. Lauko, and D. Brockway, *The Nation's Report Card: Science 2005* (NCES 2006-466) [National Assessment of Educational Progress] (U.S. Department of Education, National Center for Education Statistics, Washington, D.C., 2006). Available at: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2006466.
18. A. M. Kelly and K. Sheppard, "Secondary school physics availability in an urban setting: Issues related to academic achievement and course offerings," *Am. J. Phys.* **77**, 902-906 (2009).
19. Michael Neuschatz, Mark McFarling, and Susan White, *Reaching the Critical Mass: The Twenty Year Surge in High School Physics; Findings from the 2005 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2008), p. 44. Available at: http://www.aip.org/statistics/trends/reports/hs05report.pdf.
20. J. S. Passel and D. Cohn, *U.S. Population Projections: 2005-2050*. (Pew Research Center, Washington, D.C., 2008). Available at: http://pewhispanic.org/reports/report.php?ReportID=85.
21. While the student population is becoming more diverse, this is not reflected in the teaching workforce. Only about 3% of high school physics teachers are African-American or Hispanic. See p. 16 of Neuschatz et al., *Reaching the Critical Mass* (Ref. 19).

social decisions requires ever-increasing levels of scientific and technological understanding.

Impact on students' choice to pursue Science, Technology, Engineering and Math (STEM) careers

Several recent reports underline the importance of high school physics in influencing career choices at the post-secondary level. For example, a study commissioned by Microsoft surveyed undergraduate college students who are pursuing a Science, Technology, Engineering and Math (STEM) degree. The overwhelming majority of these students (78%) reported that they had decided to study STEM *before* they entered college, and a clear majority had made the decision while they were still in high school. More than half reported that it was "a teacher or class" that got them interested in STEM.[22] (This was consistent with a 1970 study which showed that 44% of physics majors had chosen science as their major field of interest during high school, and that 95% made the decision before entering college.[23]) Another study examined Florida high school graduates who had gone on to earn bachelor's degrees from 4-year public universities in Florida. Of those graduates who had taken high school physics, 19% had earned their bachelor's degree in a STEM field, more than double the rate for students who had not taken physics.[24] In view of the nation's growing need for STEM workers, such findings strongly suggest that it is increasingly critical to focus attention on the state of high school physics instruction.

Poor physics instruction in high school sets up a downward spiral that, without intervention, will continue to perpetuate itself. As a result of weak or non-existent high school physics classes, few high school students are inspired to pursue further study of physics. This limits the number of future college physics majors, and thus the supply of qualified high school teachers. The vicious circle is often completed by state accreditation agencies that respond to the shortage by setting a low bar for acquiring an endorsement to teach high school physics, thereby propagating a legacy of mediocrity.

22. Harris Interactive, *STEM Perceptions: Student and Parent Study* (Microsoft/Harris Interactive, 2011). Available at: http://www.microsoft.com/presspass/presskits/citizenship/docs/STEM_Perception_Report.pptx.
23. W. Rodman Snelling and Robert Boruch, "Factors influencing student choice of college and course of study," *Journal of Chemical Education* **47**, 326-330 (1970).
24. W. Tyson, R. Lee, K. M. Borman, and M. Ann Hanson, "Science, Technology, Engineering, and Mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment," *Journal of Education for Students Placed at Risk* **12**, 243-270 (2007).

Societal and funding implications for the physics community

The state of high school physics affects the overall health of the physics profession. The shortage of adequately prepared physics teachers limits high school student achievement in physics, interest in physics, and motivation to pursue physics in college. The resulting small supply of potential physics majors has had a significant and increasingly damaging impact on college and university physics departments. In fact, about half of all college and university physics programs award fewer than 5 bachelor's degrees per year.[25] Moreover, the fraction of undergraduate STEM degrees awarded to physics majors has decreased substantially over the last several decades (see Figure 4).[26] Small numbers of undergraduate physics majors make it difficult to justify a more substantial faculty and other resources for physics departments. Moreover, an increasing number of physics degree programs have come under threat of closure due to low enrollments. The overall small number of physics bachelor's also limits the ability of physics doctoral programs to attract qualified U.S. graduate students. Despite a recent uptick, the number of U.S. citizens who earn a physics Ph.D. has declined since a peak in the early 1970s, and more than half of physics Ph.D.s granted by U.S. institutions from 2002-2008 were awarded to foreign citizens.[27] Since global competition for top science talent is increasing,[28] the low proportion of U.S. citizens among the ranks of doctoral degree holders raises a concern for the future of the U.S. physics enterprise.

> **"The state of high school physics affects the overall health of the physics profession."**

25. Patrick Mulvey and Starr Nicholson, *Physics Undergraduate Degrees: Results from the 2008 Survey of Enrollments and Degrees* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/physund08.pdf.
26. Data source: National Science Foundation, National Center for Science and Engineering Statistics, Integrated Postsecondary Education Data System (IPEDS) Completion Survey, Integrated Science and Engineering Resources Data System (WebCASPAR). Available at: http://www.webcaspar.nsf.gov/.
27. Patrick Mulvey and Starr Nicholson, *Physics Graduate Degrees: Results from the Enrollments and Degrees & the Degree Recipient Follow-up Surveys* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/physgrad2008.pdf.
28. National Science Board, *Science and Engineering Indicators 2012* [NSB 12-01] (National Science Foundation, Arlington, VA, 2012), "Higher Education in Science and Engineering." Available at: http://www.nsf.gov/statistics/seind12/c2/c2h.htm.

Maintaining the status quo for physics teacher preparation risks producing a citizenry that fails to appreciate and support physics. Although the evidence cited above suggests that good high school physics classes can motivate students to pursue physics or other STEM studies in college, most students enrolled in high school and college physics courses have no intention of pursuing advanced physics studies. Poor instruction increases the likelihood these students will have a negative experience with physics or avoid it altogether. Lack of positive exposure to physics is likely to result in apathy toward the field and public support of work done by physicists.

Recent calls to action

A number of studies and reports in the past decade have highlighted problems associated with STEM education in the United States. Perhaps the most compelling and widely cited is the 2007 report "Rising Above The Gathering Storm"[29] from the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. This report makes clear that failing to invest in basic sciences and mathematics is a significant threat to American competitiveness. First among the report's recommendations is to annually recruit 10,000 of America's brightest students to become science and mathematics teachers. In 2010, the President's Council of Advisors on Science and Technology (PCAST) echoed this recommendation in its report on improving K-12 education in Science, Technology, Engineering, and Math.[30] Beyond mere numbers of teachers, however, the nation needs *high quality* STEM instruction. In support of this goal, the first recommendation of the February 2012 PCAST report is a call for the nation to catalyze widespread adoption of empirically validated teaching practices.[31] Many other recent reports have echoed these calls to take urgent action to improve U.S. STEM education.[32]

29. Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology; Committee on Science, Engineering, and Public Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academies Press, Washington, D.C., 2007) Available at: http://www.nap.edu/catalog.php?record_id=11463#toc.
30. President's Council of Advisors on Science and Technology, *Report to the President, Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future* (Executive Office of the President, Washington, D.C., 2010). Available at: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf.
31. President's Council of Advisors on Science and Technology, *Report to the President, Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics* (Executive Office of the President, Washington, D.C., 2012). Available at: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf.
32. See Appendix on Resources for an extensive bibliography of reports on U.S. STEM education.

A national response

Already, the government, universities, businesses, and other organizations have responded to the call for improving STEM education. In recent years the budget for the congressionally mandated Robert Noyce Teacher Scholarship program for prospective STEM teachers has grown considerably.[33] The National Math and Science Initiative is replicating the UTeach program for educating more math and science teachers at universities and colleges across the nation.[34] The Association of Public and Land-Grant Universities has launched the Science and Mathematics Teacher Imperative to improve STEM teacher preparation.[35] Through the Physics Teacher Education Coalition (PhysTEC), the American Physical Society and the American Association of Physics Teachers have increased substantially the number of physics teachers at PhysTEC-supported sites and raised awareness on issues related to physics teacher education throughout the physics community.[36,37] Indeed, each of these programs is a step in the right direction. But many more physics teachers are needed than can be prepared by these programs alone.

"...the overwhelming majority of students come to college without a deep understanding of foundational ideas in physics."

The challenge of improving physics teacher education

Many high school physics teachers have a profoundly positive effect on their students' understanding of and appreciation for the subject. Research shows, however, that many high school physics courses are not effective: the overwhelming majority of students come to college without a deep understanding of foundational ideas in phys-

33. Division of Undergraduate Education, *Robert Noyce Teacher Scholarship Program.* (National Science Foundation, Arlington, VA, 2011). Available at: http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5733.
34. *National Math and Science Initiative.* Available at: http://www.nationalmathandscience.org/index.php/uteach-programs/uteach-program.html.
35. Association of Public and Land-Grant Universities, *Science and Mathematics Teacher Imperative*. Available at: http://www.aplu.org/page.aspx?pid=584.
36. *Physics Teacher Education Coalition*. Available at: http://www.phystec.org/.
37. The American Chemical Society is also taking steps to address the severe shortage of qualified chemistry teachers and has launched the Chemistry Teacher Education Coalition, modeled after PhysTEC. See: http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_SUPERARTICLE&node_id=888&use_sec=false&sec_url_var=region1&__uuid=-2f29ae7f-c5e4-49b5-8c5a-b1546e5ef0c1.

ics,[38] and high school physics students have no greater success in introductory college physics courses than students who instead took high school calculus.[39] To be sure, the nation needs more teachers who themselves have a strong background in physics. At least as important, however, is the need for university-based educators to educate future teachers in a way that will enable these teachers to help their own students develop a deep understanding of physics. In addition to recruiting some of the most talented physics majors to teaching careers, the challenge is to identify the knowledge, skills, and dispositions of exemplary physics teachers, and to build education programs that focus on the development of these qualities in teachers in sufficient numbers to meet the nation's need.

T-TEP charge

In response to the shortage of physics teachers in the United States and concerns over their effectiveness, the American Physical Society, American Association of Physics Teachers, and American Institute of Physics formed the Task Force on Teacher Education in Physics (T-TEP). T-TEP was charged with documenting the state of physics teacher preparation and making recommendations for preparing teachers for the 21st century. Specifically, T-TEP investigated ways of *increasing the number of qualified teachers* by looking for generalizable, yet flexible, strategies that institutions—and in particular physics departments and schools or colleges of education—can employ; *best practices* that thriving physics teacher education programs employ; and *research, policy, and funding implications* of these investigations for the nation.

In order to design a focused and in-depth study, the scope of the charge was limited to physics teacher preparation. Undoubtedly, improving U.S. science education also includes addressing issues of teacher intellectual autonomy, salaries, and retention.[40,41] However, a critical piece of the solution involves the institutions that recruit and prepare physics teachers. This report identifies specific problems with physics teacher preparation in the U.S. and offers an integrated set of recommendations to improve it.

Outlook for the future, informed by the past, rooted in present initiatives

As T-TEP was conducting its investigation, it became clear that it was not the first body to look carefully at the state of physics teacher preparation in the United States and issue recommendations for improvement. The section entitled "Foundational Material I: Historical Context" collects the most relevant reports that have been written on the subject since 1880 and underscores similarities among some of the recommendations. We are cautiously optimistic that the recommendations of the present report will not go unheeded as have those of most previous reports. There are four important historical and contextual differences that inform our optimism. First, the demand for specialized physics teachers (teachers who spend most or all of their time teaching physics), both in absolute numbers and in the proportion of all those assigned to teach physics, is at the highest level ever. Second, the fingers of global competition have reached every community in this country and are knocking loudly on the doors of higher education in ways that were unthinkable even a few years ago. Third, professional societies have launched significant national efforts of unprecedented scope to help the nation meet its STEM education challenges. Finally, the advent of physics education research and research on physics teacher education have placed recommendations on a firmer scholarly footing than ever before. These factors are catalyzing a response that might well be our best chance to turn around the tide of mediocrity and to place physics in its proper, well-deserved place in the U.S. education system, as a foundation of all science and as a primary means of gaining knowledge of the world.

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38. See pretest scores on diagnostic exams in college and university physics courses in R. R. Hake, *American Journal of Physics* **66**, 64-74 (1998), Fig. 1, and A. P. Fagen, C. H. Crouch, and E. Mazur, *The Physics Teacher* **40**, 206-209 (2002), Fig. 2.
39. P. M. Sadler and R. H. Tai, "The two high-school pillars supporting college science," *Science* **317**, 457-458 (2007). Available at: http://www.sciencemag.org/content/317/5837/457.summary.
40. B. Auguste, P. Kihn, and M. Miller, *Closing the Talent Gap: Attracting and Retaining Top-Third Graduates to Careers in Teaching, An International and Market Research-Based Perspective* (McKinsey & Company, New York, 2010). Available at: http://www.mckinsey.com/clientservice/Social_Sector/our_practices/Education/Knowledge_Highlights/~/media/Reports/SSO/Closing_the_talent_gap.ashx.
41. R. M. Ingersoll and H. May, *The Magnitude, Destinations, and Determinants of Mathematics and Science Teacher Turnover*. (Consortium for Policy Research in Education, 2010). Available at: http://www.gse.upenn.edu/pdf/rmi/MathSciTeacherTurnover.pdf.

Chapter 2: Data Sources and Methodology

T-TEP engaged in a wide variety of data-gathering activities—exploring all known and available sources of relevant information—to investigate the status of physics teacher education and to document exemplary programs. Those physics teacher education programs that appeared to be performing at the highest level were probed by T-TEP more deeply than had been reported in any previous investigations. This chapter provides a brief description of the primary data sources and data-gathering methods.

Goals for data gathering included:

- ascertaining the number of physics teachers produced per institution per year for all U.S. institutions
- characterizing major features of active physics teacher education programs
- documenting in detail some of the most successful physics teacher education programs

Data from States

T-TEP contacted teacher-certification departments in all 50 states and the District of Columbia to gather data on the number of teachers newly certified to teach physics. These departments were asked to provide the number of initial certifications in physics granted per institution per year for the previous 6 years, (2001-2007 in most cases). As each state has its own standards and types of certification (e.g., certification in physics, physical science, general science, etc.), T-TEP asked for a list of certifications that would allow a teacher to teach high school physics as well as for a count of all such certifications awarded at each institution each year. While some states offer a general science certification, T-TEP asked states not to include these in their counts of physics certifications because such certifications were deemed too broad to indicate sufficient preparation to teach physics.

In total, 36 states responded. Some reported, however, that they did not gather the information requested, or they did not have the resources to generate the requested report. Some reported that they only offered a general science certification and did not have a certification more specific to physics. In some cases, states could provide data only on the number of recommendations for licensure or program completers, and T-TEP accepted this as a proxy for the number of initial physics certifications. In sum, there were useable data from 17 states.

Data from Schools of Education

T-TEP contacted the American Association of Colleges of Teacher Education (AACTE), which generously shared data from its approximately 700 members. The data consisted of the number of graduates from physics education programs each year for the academic years 2004-2005 and 2005-2006. T-TEP totaled the number of students who completed programs leading to initial certification, including bachelor's, post-baccalaureate, and masters programs; students who completed programs for advanced certification and other programs were not included. Eight institutions were removed from the data set due to suspected errors in self-reported data; if the change in the number of initial certifications between the two academic years was 10 or greater, the data from the institution were excluded.

Survey of Physics Department Chairs

T-TEP contracted with the Statistical Research Center (SRC) of the American Institute of Physics to conduct a survey of physics departments about teacher education efforts. T-TEP decided that the survey should focus primarily on programs in physics departments that were intended to prepare undergraduate physics majors for high school physics teaching.[1] SRC staff members collaborated with T-TEP members to develop a survey instrument designed to:

- identify physics departments with physics teacher education programs;
- collect data on the number of graduates coming out of those programs and the number of faculty involved in the programs; and
- identify the extent to which these programs included features of specific interest, such as having a master teacher or a formal relationship with the school of education.

The survey instrument is in Appendix A.2; it consists of 19 multiple-choice and short-answer questions. Note that the wording of the survey questions is very specific and precise, and the statistical results must be interpreted with due caution in recognition of this precise wording. In particular, results related to undergraduate-level programs may not be generalized to graduate-level programs or programs for in-service (practicing) teachers, and vice-versa.

The survey was conducted exclusively online. T-TEP contacted all 754 departments that awarded a bachelor's in physics in 2009 and invited the chairs of those depart-

1. Physics departments were also asked about graduate-level programs or courses to prepare physics teachers; fewer than 10% reported having such programs or courses.

ments by e-mail to participate in the study. After the initial e-mail, department chairs who did not respond to the survey were contacted up to four more times during June and July of 2009. In sum, there were a total of 578 survey responses (77% response rate). Appendix A.1 contains a detailed breakdown and discussion of the survey results, written by SRC personnel.

Follow-up to Physics Chairs Survey

To verify and enrich survey data, T-TEP conducted follow-up telephone interviews and site visits; see below. In particular, T-TEP focused on the 37 institutions reporting at least four students completing a physics teacher education program during the previous two years, i.e., averaging at least two students completing such a program each year. These interviews and site visits formed the basis for T-TEP's findings about the most active pre-service physics teacher education programs.[2] Through a combination of telephone interviews and site visits, T-TEP followed up with 30 of these 37 programs (over 80%) which were graduating physics teachers at the highest rates. T-TEP also interviewed faculty members from several large physics departments that had reported low numbers of graduates, to gather comparison data and additional perspective.

When information obtained by follow-up interviews and site visits differed from survey responses, T-TEP replaced the survey response data. For example, in 16 cases the survey response data on the number of graduates from undergraduate physics teacher preparation program during the previous two years differed from that obtained from a phone interview or site visit. In all but two of these cases, the number of graduates obtained through interviews or site visits was lower than the survey response by one or two individuals.

Telephone Interviews

The purpose of the telephone interviews was twofold: to verify the information captured by the online survey and to gather further information about physics teacher education programs reporting a relatively large number of physics education graduates. T-TEP members interviewed the member of the department who was identified in the online survey as the most knowledgeable about the physics teacher education program. A standard protocol guided the interviewers' questions, but interviews typically expanded to cover a broad range of topics in considerable depth.[3]

Through the interviews T-TEP confirmed that, as noted above, there was a modest tendency to overestimate the number of program graduates, but that nonetheless the numbers supplied on the physics chairs' survey were sufficiently accurate to validate the categorization of "active program" for nearly all of the interviewed programs. This gave T-TEP confidence that the institutions interviewed were indeed among the most active pre-service physics teacher education programs in the United States. Interview responses made it clear, however, that answers supplied to certain survey questions were not reliable, including the number of faculty involved in teacher education and the degree of involvement of master teachers. T-TEP does not know the reason for this unreliability. It could have been due to misinterpretation of questions, lack of knowledge about programs, or still other unknown factors. Therefore, survey data were not reported where there were significant disagreements with interview data.

Site visits

The purpose of the site visits was to identify common elements among programs that were successful in preparing relatively large numbers of qualified physics teachers. Site-visit teams typically consisted of one T-TEP member, one professional society member, and one additional person knowledgeable about physics teacher education.

To identify sites, T-TEP first e-mailed all physics department chairs in June 2008, inviting them to nominate their physics teacher education programs for a site visit and send:

1. the name and contact information of a person knowledgeable about the program;
2. a brief description of the program and reasons it would be of interest to the community;
3. the number of high school physics teachers educated by the program during the previous five years;
4. any supplementary materials that would help describe the program.

T-TEP also e-mailed schools of education a similar request, but this generated very few responses. In addition, about a dozen programs that did not respond to the initial inquiry, but were known to T-TEP members, were contacted and invited a second time. Several additional responses came from this second round of inquiries.

T-TEP reviewed the approximately 150 total nominations and decided to consider only those programs that provided a complete pathway to certification or endorsement to teach physics. This necessarily left out many excellent programs that provide much needed professional development for in-service teachers, but do not offer a comprehen-

2. See this Report, Chapter 3: Findings.

3. The interview protocol is in Appendix A.3.

sive program to prepare new physics teachers. T-TEP also chose to consider only those programs that graduated an average of at least two physics teachers per year (termed “active programs”). This cutoff was used in keeping with T-TEP’s charge to identify strategies for recruiting and preparing relatively large numbers of physics teachers. Finally, the site selection subcommittee chose programs on the basis of perceived overall excellence and to achieve a diverse and geographically distributed portfolio of institutions, including research-intensive, comprehensive, liberal-arts, and urban-serving institutions, as well as former teachers colleges. Of the dozen programs selected for site visits, T-TEP included three programs that focus on in-service physics teacher education rather than pre-service preparation in order to provide insight on this pathway to physics teaching.

Sites were sent a detailed questionnaire about the program to be returned in advance of the site visit.[4] In addition, T-TEP sent a Memorandum of Understanding explicitly stating the terms under which the site visit was to be conducted.[5] Site visits lasted about two days, and included discussions with physics and education faculty involved in the program, their respective chairs, deans, and, in some cases, higher-level administrators. Site-visit teams also observed program classes and met with program graduates as well as current program students. Where feasible, site-visit teams also observed program graduates teaching high school students, and held discussions with the teachers’ high school administrators. After the site visit, the team wrote a detailed report of their observations. The report was shared with the entire task force and the leaders of the teacher education program to verify accuracy.

4. The site visit questionnaire is in Appendix B.4.
5. The Memorandum of Understanding is in Appendix B.3.

Additional Sources

In addition to the data-gathering activities described above, T-TEP consulted extant research results, national reports, and books on science teacher education, physics and physics teacher education, and the state of student achievement in science and related fields. T-TEP also reviewed and analyzed hundreds of relevant research papers and reports published during the past 130 years.[6] Finally, T-TEP also sought advice from teacher education experts, foundation program officers, and policy makers, and collaborated with other organizations with a shared interest in teacher education, including the Association of Public and Land-Grant Universities, Knowles Science Teaching Foundation, and American Chemical Society.

6. See “Resources for the Education of Physics Teachers” at the end of this Report.

Chapter 3: Findings

The United States' system of preparing physics teachers is inadequate to address the current and future needs of the nation's students. Indeed, there really is no "system" and, for the most part, the education of physics teachers in the U.S. is neither systematic nor efficient. T-TEP found that most U.S. physics teachers have neither a major or minor in physics, while the overwhelming majority never graduated from or even participated in any program designed to help them learn how to teach physics. Over 90% of physics teachers in the U.S. are educated in programs that are not designed to offer coherent or systematic preparation in classroom physics teaching. Most students in these programs do not have the benefit of mentoring by expert physics teachers, and do not receive any early experiences in actual physics teaching. They are not exposed to the wealth of modern research on physics learning or to the vast array of research-based physics curricula and instructional methods developed in recent decades. Instead, they are left to find their own way in programs that are largely ad hoc, and that provide little guidance before or after students begin their teaching careers. Consequently, most physics teachers develop their skills through on-the-job practice, teaching a subject that they never intended to teach, nor were trained to teach. All of this is in dramatic contrast with typical practice in many other nations, in which preparation of physics teachers is thoroughly systematized, strongly supported, and highly valued.

"...most physics teachers develop their skills through on-the-job practice, teaching a subject that they never intended to teach, nor were trained to teach."

T-TEP made the following eight findings. The first finding is split into two interrelated statements.

1(a). Few physics departments and schools of education are engaged in the professional preparation of physics teachers.

In a nationwide survey, T-TEP found that only 20% of all physics departments are actively engaged in physics teacher education (PTE),[1] defined as having a PTE program that had graduated at least one student in a recent two-year period.[2] Figure 5 on the next page provides more detail regarding the 578 physics departments that responded to the survey (this corresponded to a 77% response rate). While 36% of physics departments reported having a PTE program, barely over half of these reported any recent graduates, suggesting they have a program that existed only on paper. Others reported a program elsewhere on campus; however, the lack of close connection with the physics department likely limited the effectiveness of many of these programs in recruiting physics students.

Following a similar pattern, only 23% of schools of education belonging to the American Association of Colleges for Teacher Education (AACTE) reported a program with PTE graduates over a recent two-year period.[3] Many of these were the same programs reported by physics departments, since institutions typically have joint programs in which students take content courses in physics and complete certification requirements in education. Data collected from state education agencies echoed the data from physics departments and schools of education; about half of the nearly 500 institutions for which there were data reported no physics certifications in a recent two-year period.[4] This is particularly striking in view of the fact that mere certification to teach physics is typically a lower bar than graduation from a PTE program, since requirements for state certification can be as little as passing a single exam or taking a very small number of physics courses.

1(b). Physics teacher education programs produce very few graduates, making it difficult to justify dedicated staff, specialized courses, and other resources.

In all data sources consulted, T-TEP found very few students graduating from PTE programs; the vast majority of programs have fewer than two graduates per year, and

1. There are multiple pathways to becoming a physics teacher with varying state standards and certification requirements. Hence, for the purposes of this report and to standardize the data, T-TEP agreed that (whenever possible) it would count as qualified new physics teachers only those individuals who had a major or minor in physics or an equivalent amount of course work, and who had met the necessary requirements for physics teacher certification or endorsement in their state.
2. In the T-TEP survey, a PTE program was defined as a track, concentration, or specialization designed to prepare students for high school physics teaching. See Appendix A for a full report on the survey.
3. Private communication from the American Association of Colleges for Teacher Education.
4. States reporting physics certification data by institution and by year included CA, CT, FL, IL, IN, LA, MA, MD, MN, ND, NH, NY, OH, TX, WA, WI, and WV.

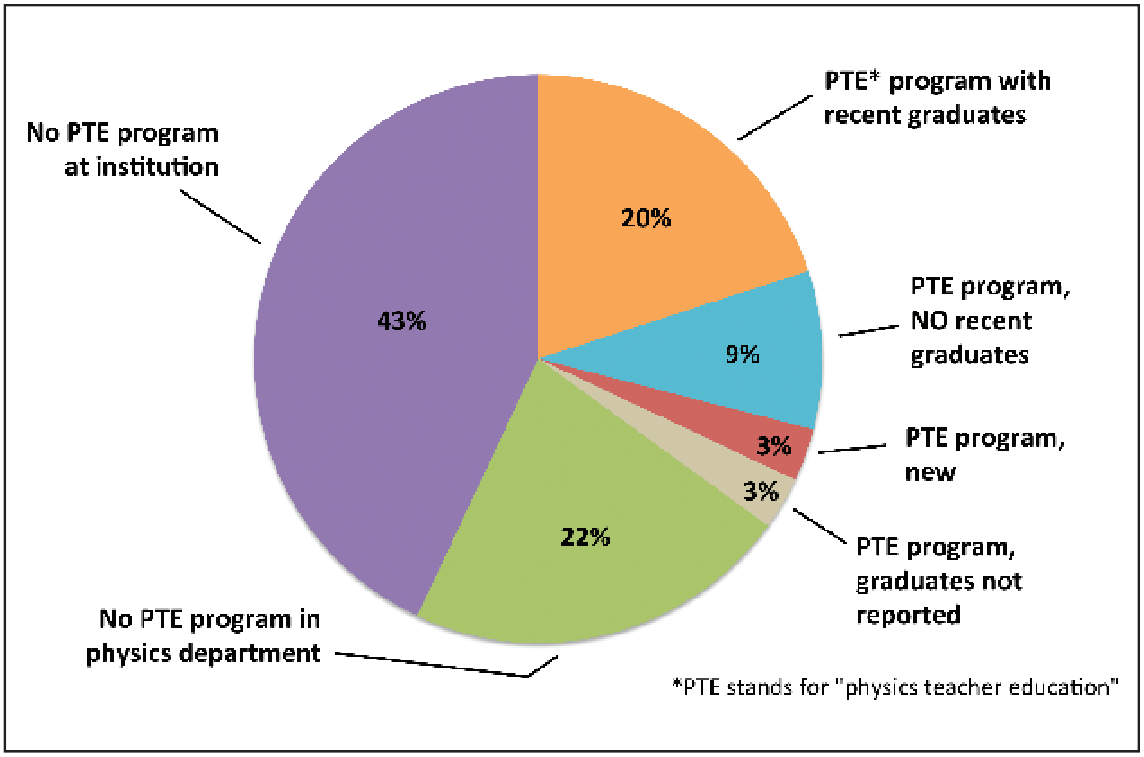

Figure 5. Engagement of physics departments in teacher education

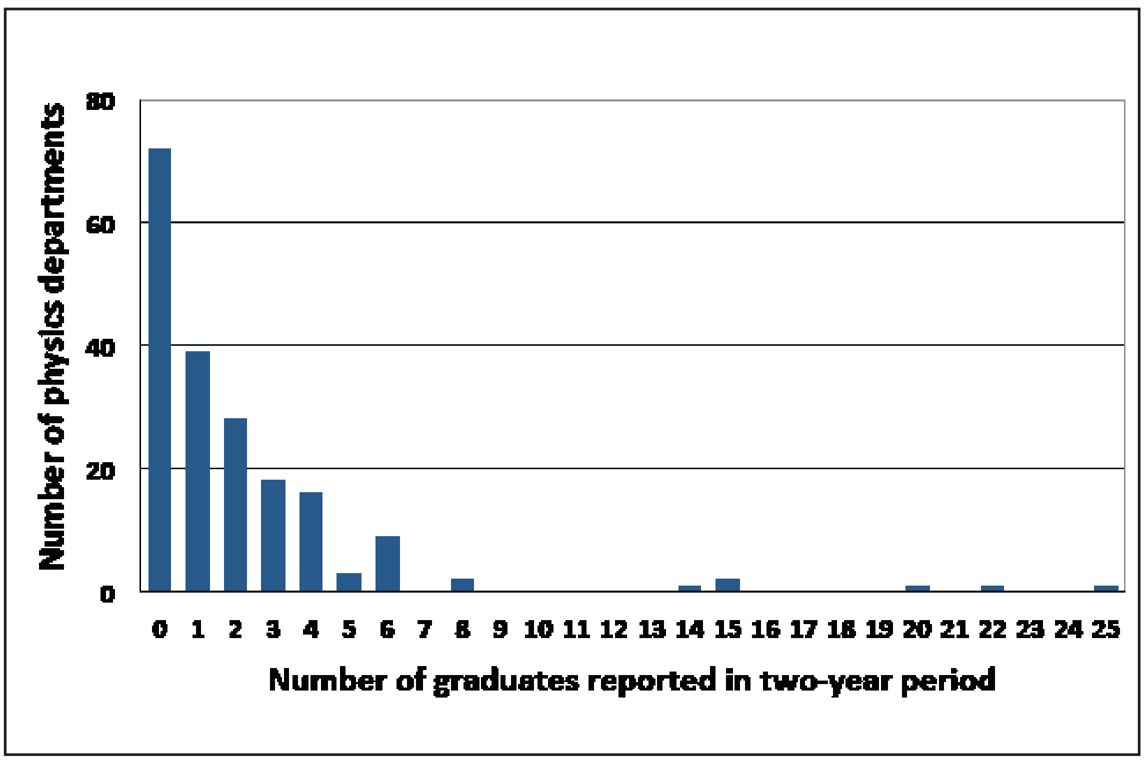

Figure 6. Distribution of graduates from teacher education programs in physics departments

the most common number of graduates is zero. Figure 6 shows the distribution of PTE graduates as self-reported in the physics department survey. This distribution is severely skewed toward low producing programs, which is also true of the other data sets T-TEP examined. If an "active program" is defined as averaging just two or more PTE graduates per year, only 37 physics departments make that cut, that is, 7% of all responding departments.[5] Very nearly all physics departments reported four or fewer PTE graduates per year. Just six programs exceed this cutoff, ranging from 7 to 13 PTE graduates per year.

With such low numbers of students, administrators very likely regard PTE programs as having low priority. Our conjecture was that the low numbers would make it difficult for departments to justify acquiring or assigning staff with expertise to lead such programs or offer courses specific to physics pedagogy. Telephone interviews conducted with active programs in physics departments substantiated this conjecture. Lower producing programs likely fare even worse. This raises concerns about the quality of the preparation received by future physics teachers.

A likely factor contributing to the very low numbers of PTE graduates was that most physics departments do not carry out substantial formal recruitment efforts specific to their PTE program. In telephone interviews with the active programs, T-TEP found that while physics departments typically listed and promoted all degree tracks, few directly encouraged students to become high school teachers or sought and identified students who had an interest in teaching. Recent studies suggest that active recruiting by faculty may significantly increase the number of students considering a teaching career. [6]

2. Without exception, all of the most active physics teacher education programs have a champion who is personally committed to physics teacher education. With few notable exceptions, these program leaders have little institutional support.

Every single active PTE program has at least one faculty member who served as its champion. These champions are personally committed to physics teacher preparation. They are usually the primary advisors and mentors to physics education students during the time those students are involved with the physics department.[7] The champions typically work to improve coherence among physics department offerings, school of education requirements, and state certification requirements. They take advantage of or expand flexibilities in the system in order to optimize programs for individual students. Champions also seek out whatever resources might be available to support the program, and tend to be advocates for the program within the department and, if they have access, with university administrators.

It became apparent early in T-TEP's investigation that a champion is central to the success of a PTE program. Most institutions with active programs have a single champion. At a few institutions, a team of individuals is committed to physics teacher preparation, such as one physics and one education faculty member, or two physics faculty members. In such cases the roles of the champion are shared among the team members. In a few other cases, the champion creates a position or positions to run the PTE program on a day-to-day basis, which allows the champion to focus on building and maintaining departmental and institutional support. At a few institutions, the champion has extensive high-school physics teaching experience, but more often they have little or none. In a very few cases, there are active programs where the PTE program still enjoys the residual benefits of a champion who had recently left the institution; however, in such cases it appears that the number of students enrolled in the PTE program has decreased. In most cases, institutional and departmental recognition and support for the champion as well as for the PTE program is minimal and not commensurate with the amount of work involved. Indeed, fewer than 30% of physics chairs reported any recognition, support, or tangible rewards

"...fewer than 30% of physics chairs reported any recognition, support, or tangible rewards for faculty members involved in their department's PTE program."

5. There were 176 physics departments that did not respond to the T-TEP survey, and a few of these might have also fit the definition of an "active program," i.e., averaged two or more PTE graduates per year. Late responders to the survey were more likely to be programs that produced very few or no graduates, and T-TEP hypothesized that non-responders were similar to the late-responders in that regard. This implies that the fraction of non-responders with an "active program" was likely to be less than that of responders. Consequently, T-TEP is fairly confident that there are a *total* of at most 50 "active programs" in the nation (at least 2 graduates per year) in which the physics department was strongly involved.
6. For example, V. Otero, S. Pollock, and N. Finkelstein. "A physics department's role in preparing physics teachers: The Colorado learning assistant model," *American Journal of Physics* **78**, 1218 (2010).
7. Advising responsibility typically transferred to the school of education as students completed their physics degree or began student teaching.

Where do new physics teachers come from?

Each year, about 3,100 teachers[1] find themselves at the front of a high school physics classroom for the first time. Yet, the total number of PTE graduates reported by physics departments, around 200 per year,[2] is tiny in comparison. Similarly, schools of education belonging to AACTE report about 270 PTE graduates per year,[3] a number that likely includes many of the same PTE graduates counted by the physics departments. Where do all the new teachers of physics come from, if not from PTE programs?

These 3,100 new physics teachers fall into two broad categories: (1) those who are brand new to any sort of high school teaching, and (2) experienced in-service high school teachers who are teaching physics for the first time. Most new teachers of physics had little connection with physics departments in their preparation; about a third of those new to high school teaching have a degree in physics or physics education.[4] These new teachers enter the physics classroom through a variety of pathways, including earning a general science certification that allows them to teach physics, taking a physics content exam (of variable quality and cutoff score) without having completed a physics degree, or receiving a temporary or emergency certification. However, even the 32% with a degree represent far more than the number estimated to have graduated from PTE programs in physics departments. Some students get a traditional physics degree and after graduation choose to enter a teacher certification program; these students would likely not be counted among physics PTE graduates. An even more significant source of physics teachers appears to be the so-called "career changers:" AIP reports that over half of all those first-year physics teachers who are new to high school teaching appear to be second-career teachers, entering teaching at a median age of 30.[5] Many of these second-career teachers enter through alternative certification programs;[6] such programs typically have only a loose affiliation with a college or university, if any, and tend to be poor quality.[7]

It is also important to realize that over half (about 1,700) of the new teachers of physics are actually in-service teachers who taught other subjects before starting to teach physics.[8] The large number of in-service teachers newly assigned to physics reflects, in part, the degree to which science teachers are reassigned to meet changing staffing needs.[9] For example, a school that needs to add one or two sections of physics often finds it easier to assign these to a teacher already on staff than to hire a new teacher. It also partly reflects the unmet demand for more physics teachers created by teacher retirements and by growth in the number of high school students taking

1. Susan White and Casey Langer Tesfaye, *Turnover Among High School Physics Teachers* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/hsturnover.pdf.
2. This value is found by summing the numbers of graduates represented in Fig. 2. If 176 non-responding physics departments are included, the total number of PTE students graduating from physics department programs can be estimated to be at most 270 per year.
3. Source: Private communication from AACTE.
4. The precise figure was 32% in 2005 and is little changed since then; see pp. 17 and 38 in: Michael Neuschatz, Mark McFarling, and Susan White, *Reaching the Critical Mass: The Twenty Year Surge in High School Physics; Findings from the 2005 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2008). Available at: http://www.aip.org/statistics/trends/reports/hs05report.pdf. The educational background of physics teachers who are new to high school teaching (i.e., the proportion with majors in physics or physics education) is very similar to the background of all physics teachers. Moreover, the total proportion of teachers with a major or minor in physics or physics education has been fairly stable for about 20 years; see: Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010). Available at: http://www.aip.org/statistics/trends/reports/hsteachers.pdf.
5. See page 37 in: Michael Neuschatz, Mark McFarling, and Susan White, *Reaching the Critical Mass: The Twenty Year Surge in High School Physics; Findings from the 2005 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2008). Available at: http://www.aip.org/statistics/trends/reports/hs05report.pdf.
6. T-TEP did not seek to study or collect data from alternative certification programs due to the wide variation among these programs, and because many of them are independent of colleges and universities.
7. David Haselkorn and Karen Hammerness, *Encore Performances: Tapping the Potential of Midcareer and Second-Career Teachers* (Woodrow Wilson National Fellowship Program, Princeton, NJ, 2008). Available at: http://www.woodrow.org/images/pdf/policy/EncorePerformances_0908.pdf.
8. The majority of these in-service teachers taught two to five years before starting to teach physics: Susan White and Casey Langer Tesfaye, *Turnover Among High School Physics Teachers* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/hsturnover.pdf.
9. These needs reflect both changes in student enrollment and losses of teachers to retirement or to transfers out of physics teaching; see Ref. 10.

physics.[10] Figure 7 summarizes the factors contributing to the annual turnover of high school physics teachers.

The multitude of pathways that lead to the physics classroom, and their widely varying quality, present a challenge for physics teacher educators. Many, if not most, of these pathways do not adequately prepare teachers of physics with respect to content and pedagogy. Furthermore, the great majority of future physics teachers, especially those who are underprepared, are invisible to physics departments and schools of education since these teachers do not participate in designated PTE programs and may not otherwise identify themselves. There is a long and continuing tradition of attempting to address this problem by providing professional development programs for practicing teachers; indeed, a few effective in-service professional development programs do exist.[11] However, T-TEP believes that without greatly improving the number and quality of both pre-service and in-service programs, the nation's universities will not be able to provide an adequate pool of qualified candidates for schools looking for their next physics teacher.

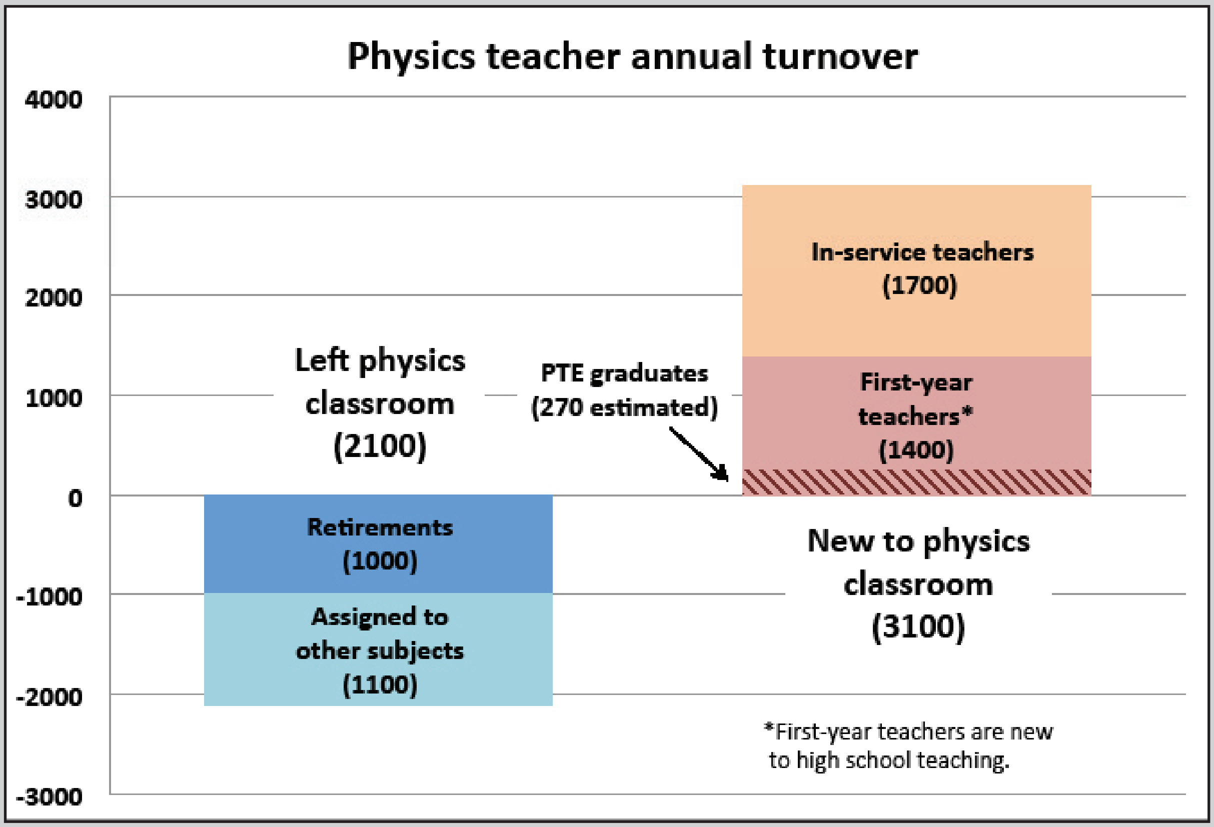

Figure 7. Physics teacher annual turnover

10. About 1000 physics teachers retire or leave teaching each year: Susan White and Casey Langer Tesfaye, *Turnover Among High School Physics Teachers* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/hsturnover.pdf. In addition, about 1100 teachers each year stop teaching physics but continue teaching in high school, a significant source of turnover in the physics teacher workforce. These 1100 teachers are permanently reassigned to other subjects and do not return to teaching physics. Source: private communication with Susan White, AIP Statistical Research Center. Nonetheless, the total number of physics teachers has recently been growing by about 1000 teachers per year, spurred on by an ever-increasing number of high school students taking physics: Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010). Available at: http://www.aip.org/statistics/trends/reports/hsteachers.pdf.

11. For example, G. Amann, J. Mader, K. J. Matsler, and J. Nelson, "AAPT/PTRA—A Part of the Solution," *The Physics Teacher* **49**, 560 (2011)

for faculty members involved in their department's PTE program. Many champions stated that lack of time and/ or resources are barriers to improving their program. The consistent absence of support for these champions reflected a widespread lack of institutional commitment to the preparation of qualified physics teachers.

3. Institutional context appears to be a significant factor in the engagement of physics departments in physics teacher education.

Not surprisingly, larger institutions as well as larger physics departments are somewhat more likely to have at least one PTE graduate in a recent two-year period. However, size is by no means the only significant factor. A linear model showed that only 5% of the variation in the number of PTE graduates could be explained by the number of physics bachelor's degrees a department granted.[8]

Another significant factor is the highest degree awarded by the physics department. About 23% of bachelor's- and master's-granting departments reported at least one PTE graduate in a recent two-year period, compared to only 13% of Ph.D.-granting departments. Moreover, students from bachelor's- and master's-granting departments make up three-quarters of the total number of PTE graduates, but only about half of all physics bachelor's.[9] There are a number of possible reasons for the greater engagement of bachelor's- and master's-granting departments, including these departments' sense of their mission as well as the interests of students that attend such institutions.

T-TEP also observed that many active PTE programs were at colleges and universities that had historical or current reputations as teacher-preparation institutions, including former normal schools and teachers colleges. The data are insufficient to confirm this link with certainty; however, it seems reasonable that institutions with a strong reputation for preparing teachers would tend to attract students interested in becoming teachers, or that physics departments as well as university administrators would be influenced by this context.

4. Few institutions demonstrate strong collaboration between physics departments and schools of education.

The vast majority of physics departments with a PTE program (about 90%) reported they have a relationship with the school of education on their campus. In fact, 80% of these departments named a contact in the school of education. However, in most cases this relationship does not appear to go very deep. Follow-up phone interviews with active PTE programs revealed that the connection with the school of education typically consisted of mutual awareness and occasional meetings. Some physics departments with active PTE programs reported participation in a program accreditation review with respect to the content courses required for pre-service physics teachers. Even in cases where the physics department and school of education share mutual respect and a common sense of purpose, most physics departments reported little regular communication with the education schools.

Lack of close collaboration between physics and education appears to compromise the quality of the PTE program and result in an incoherent experience for students. Typically, once PTE students begin to focus on their education coursework, physics departments have no further role in advising these pre-service students. The student teaching experience is usually managed entirely by the school of education, without any involvement from the physics department. Responsibilities of the school of education include finding classrooms in which to place student teachers, as well as observing and supervising student teachers. Since it is uncommon to find physics teaching expertise located in a school of education, this means that student teachers are typically not evaluated by expert physics teachers.

5. Physics teacher education programs do little to develop the physics-specific pedagogical expertise of teachers.

Even among active PTE programs, most do not have formal coursework on physics-specific pedagogy. The few programs that do have formal instruction in physics pedagogy most often have a single course, and the enrollment is invariably low (fewer than 15 students). PTE programs typically drop several upper-level physics courses from the requirements for a physics major and add a number

"The few programs that do have formal instruction in physics pedagogy most often have a single course..."

8. The correlation coefficient between number of PTE graduates and number of physics bachelor's was ≈ +0.23.
9. Patrick J. Mulvey and Starr Nicholson, *Physics Undergraduate Degrees: Results from the 2008 Survey of Enrollments and Degrees* (American Institute of Physics, College Park, MD, 2011). Available at: http://www.aip.org/statistics/trends/reports/physund08.pdf.

of education courses. Education courses reflect the broad range of state certification requirements for high school teachers. These often include a course on methods of teaching secondary science; however, such courses do not focus on teaching physics or any other specific discipline. Student teaching is always a formal requirement, although sometimes it is omitted in emergency or alternative routes to certification.

Some programs find informal opportunities for students to learn physics pedagogy. Many of these programs find positions for students as teaching assistants, lab assistants, physics tutors, or a similar physics teaching role. In the best cases, students also receive mentoring to support the development of their pedagogical knowledge and skills. A number of programs offer a seminar-style course in which pre-service students visit (and in some cases assist) local high school physics classes and reflect on their experiences.[10]

6. Few programs provide support, resources, intellectual community, or professional development for new physics teachers.

Very few active PTE programs in physics departments keep track of their graduates once they leave the program. While many champions express the desire to do so, most admit that they do not have the required time and resources. Instead, the most common form of communication reported between physics departments and their PTE graduates was e-mail or a phone call initiated by the graduate seeking help or advice from a department member, usually the champion. While it is more common for schools of education to track their graduates, physics departments are almost entirely unaware of whether this was happening at their institutions.

If programs do not track their graduates, they cannot provide mentoring, professional development and other support critical to the success and retention of new teachers. This is especially important for physics teachers, most of whom are the only one in their school[11] and cannot go to a colleague down the hall for help with even basic questions about teaching physics.

10. In many states, schools of education are required to coordinate and supervise early field experiences for all pre-service teaching candidates. In these cases, however, the experience is rarely physics-related and the physics department typically has neither knowledge of nor authority over the experiences.

11. In over 80% of the schools where physics is taught, there is only one teacher teaching the subject: Casey Langer Tesfaye and Susan White, *High School Physics Teacher Preparation* (American Institute of Physics, College Park, MD, 2012). Available at: http://www.aip.org/statistics/trends/reports/hsteachprep.pdf.

7. Few institutions offer a coherent program of professional development for in-service teachers, even though most current physics teachers are not adequately prepared to teach physics.

While investigating pre-service programs, T-TEP identified[12] about a dozen institutions with programs to prepare in-service teachers to teach physics.[13] In contrast to isolated workshops and courses, these programs offer a substantial and coherent pathway for in-service teachers to get training needed to teach physics and/or earn a credential.[14] Unfortunately, the questions in the T-TEP survey did not anticipate the wide variety of such in-service programs; consequently, it is difficult to give a quantitative estimate of their total number. However, given the very large number of underprepared physics teachers—about 15,000 without any type of physics degree,[15] let alone knowledge of physics pedagogy—we claim with confidence that the number of in-service programs is not nearly sufficient to meet the need.

Most of the in-service programs contacted by T-TEP stated that they graduate at least 5 physics teachers per year, and a few 10 or more. However, the definition of "graduate" for such programs is often ambiguous, since neither a formal degree nor certification is necessarily a goal. Still, while not all graduates might count as new physics teachers, these numbers are several times larger than typical numbers of graduates for pre-service programs.[16] In addition, course

12. T-TEP learned about in-service teacher education programs while soliciting nominations for site visits, surveying physics chairs, and conducting follow-up phone interviews.

13. A few of these in-service programs are profiled in Appendix C.

14. Programs that train in-service teachers to teach physics take many forms and have varying objectives, from updating teacher competency to enabling teachers to obtain state credentials. While acknowledging the value of all these efforts, and in order to be consistent with its investigation of pre-service programs, T-TEP decided to focus only on programs that offered a substantial and coherent pathway that incorporated in-depth preparation consisting of several related courses. In some cases these might form the basis for obtaining a degree or credential, even if most program participants did not actually seek such a degree or credential. In other cases, there was no degree or credential available (perhaps due to state credentialing requirements), but the program was judged to be comparable to other programs that did offer credentialing. Henceforward in the text, "in-service program" is understood to refer to such programs.

15. There are 27,000 teachers of physics and 46% have a major or minor in physics or physics education, which leaves 15,000 without any physics degree: Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010). Available at: http://www.aip.org/statistics/trends/reports/hsteachers.pdf.

16. These numbers included teachers from a wide variety of backgrounds. Some were seeking a credential in physics, for example, middle-school or high-school teachers wanting or expecting to teach physics, or physics teachers who were "out-of-subject-area" as defined by their state. Some were currently certified physics teachers fulfilling state requirements to maintain certification (many states require a masters degree after a certain time period); others were physics teachers seeking professional advance-

enrollments are often bolstered by teachers seeking professional development rather than a credential or degree. It is not unusual for in-service programs to serve dozens of teachers on an annual basis, with the largest programs serving 100 or more. It is difficult to estimate the national impact of in-service programs given the incompleteness of the data; however, it appears that this is a significant pathway for educating new physics teachers.

Several in-service programs offer a masters degree from the school of education or the college of arts and sciences. They typically focus on material directly relevant to teaching high school physics. Many in-service programs do not require content beyond the introductory physics sequence (usually algebra-based courses), and none go beyond the equivalent of a physics minor. In addition, most programs offer at least one course that addresses physics pedagogy, and some offer as many as three or four such courses. While the physics content of many in-service programs is relatively weak and needs improvement, instruction in physics pedagogy is actually better than in typical pre-service programs, which generally lack *any* such instruction.

In-service programs are often funded through external grants, although in some cases programs are at least in part supported by tuition paid by teachers.[17] External funding appears to be much more readily available for in-service programs than for pre-service programs, continuing a tradition extending back over 60 years.[18] However, due to dependence on external funding, both the level and structure of these programs—and even their very existence—can vary from year to year.

8. Thriving physics teacher education programs exist that can serve as models and resources for other institutions.

T-TEP identified a number of thriving programs.[19] These programs were defined as "thriving" because they are highly productive, graduating at least two students per year and as many as 12 per year. They also have exceptional characteristics that impressed T-TEP as being well grounded in educational theory and as corresponding to "best practices." No program has all of the characteristics described below, but all highly productive programs have several of them.

Recognition and support for the champion

In most of the highest producing PTE programs, the efforts of faculty members who champion the program are rewarded and given substantial recognition from both the physics department and the institution. Significant course load modification as well as material and financial resources are made available to the champion for implementation of program activities. In some cases, these faculty members' efforts carry substantial weight towards promotion and tenure decisions. Simply put, institutions with the most productive PTE programs not only have a champion, but also provide the support needed to run a successful program.

Targeted recruitment of pre-service physics teachers

A number of highly productive PTE programs implement targeted recruiting efforts. Such efforts include brochures directed at high school students and teachers, regular get-togethers for students in the PTE program and those who expressed interest in the program, and methods for identifying and tracking students interested in becoming a high school physics teacher. In several cases, the champion has established an extensive network of faculty and staff to refer students who expressed any interest in teaching. Students are often assisted with the logistics of applying to the PTE program. In several of these physics departments, teaching is presented as a viable career option—not a fallback position—for even the best physics students; at the very least, top students are not discouraged from becoming high school physics teachers.

"In several of these physics departments, teaching is presented as a viable career option—not a fallback position—for even the best physics students..."

Active collaboration between physics departments and schools of education

In contrast to the norm, a few institutions have extensive interactions between the physics department and the school of education. In some cases, there is a faculty member with a joint appointment in both physics and education; in others, there is a faculty member specializing in physics ed-

ment or simply wanting to deepen their physics content and/or pedagogical knowledge.

17. Grants from federal and state agencies are common, including the NSF Math and Science Partnership (MSP) program, state MSP grants originating from the U.S. Department of Education, and funds from the federal *Elementary and Secondary Education Act* (also known as No Child Left Behind) administered by state agencies.
18. See this Report, "Foundational Material I: Historical Context of U.S. Physics Teacher Education," p. 32.
19. See Appendix C for descriptions of thriving programs visited by the task force.

ucation located in either physics or education who helps build a bridge between the two. Extensive interactions often lead to joint projects resulting in co-funding and/or joint publications. With regard to the PTE program, such interactions may include, for example, joint responsibility for course planning and student mentoring. In some cases, physics pedagogy courses are designed and implemented by both physics and education faculty; in other cases, faculty collaborate to offer physics-specific teaching experiences in local schools or other settings. In exceptional cases, physics faculty are actively involved with the school of education in placing, observing, supervising, and/or mentoring pre-service candidates who are student teaching.

A sequence of courses focused on the learning and teaching of physics
Some PTE programs include one or more courses focused specifically on physics pedagogical knowledge. These courses include, for example, research findings about students' reasoning and learning difficulties in physics, research-based physics curricula and instructional methods, history and philosophy of physics and physics education with specific applications to high-school teaching, opportunities for students to plan and present lessons to fellow students, and practical, first-hand experience with laboratory techniques and active-learning instructional methods. In some cases, this coursework is integrated with teaching experiences designed to provide opportunities for practice and further development of physics-specific pedagogical knowledge and skills.

Early teaching experiences led by the physics department
In many of the most productive PTE programs, early teaching experiences specific to physics are a regular part of the program and are required or encouraged for all participants. These experiences are led by the physics department and sometimes carried out in collaboration with the college of education. PTE students participate in instructional activities by serving as teaching assistants in laboratories, recitation sections, or in interactive lectures, or by serving as tutors for students enrolled in introductory physics courses. In some cases, PTE students are involved in teaching physics to pre-college students, for example, during outreach events or visits to local schools as part of a formal course offered by the physics department.

Individualized advising of teacher candidates by knowledgeable faculty
It is common for thriving PTE programs to offer their students individualized advising by faculty who have extensive knowledge about physics teaching as well as requirements for certification. These faculty provide professional nurturing and an intellectual home for PTE students. They are typically proactive, looking out for the needs of individual students and helping them structure their degree programs most efficiently.

Mentoring by expert physics teachers
A few physics departments engage an expert secondary-school physics teacher (or teachers) in the PTE program who mentors pre-service candidates. The expert physics teacher, sometimes referred to as a "Master Teacher," can speak from experience and offer practical advice on how to teach physics in the high school setting. In some cases this individual is still actively engaged in high school teaching while in other cases they are former or retired teachers.

"In exceptional PTE programs, faculty track and actively maintain contact with their graduates, offering ongoing support and encouragement during the initial years of teaching."

A rich intellectual community for graduates
In exceptional PTE programs, faculty track and actively maintain contact with their graduates, offering ongoing support and encouragement during the initial years of teaching. These programs often report a strong sense of community among graduates, fostered by regular gatherings led by program faculty. In addition, PTE students typically have opportunities to meet with program graduates and exchange ideas and experiences, further extending the community. The champion typically devotes considerable time and energy to building and supporting this community. In many cases, structures such as listservs are in place to facilitate communication among the various constituents of this community even as individuals leave or move away from the institution.

Chapter 4: Recommendations

These recommendations address T-TEP's findings, and reflect a synthesis of relevant results from the literature on science teacher education and development. The 12 recommendations are grouped in three categories—*commitment*, *quality*, and *capacity*. A well-recognized *commitment* to physics teacher education is necessary, as are specific efforts to improve the *quality* of teacher professional preparation systems and boost the *capacity* of institutions to educate sufficient numbers of physics teachers to meet the national need. We conclude our recommendations with a national proposal for regional centers in physics education that embody the 12 recommendations.

Commitment

Physics and education departments, university administrators, professional societies, and funding agencies must make a strong commitment to discipline-specific teacher education and support.

1. **Institutions that consider the professional preparation of science, technology, engineering, and mathematics (STEM) teachers an integral part of their mission must take concrete steps to fulfill that mission.**

   Concrete steps should include hiring or appointing a PTE program leader or leaders, i.e., specific faculty members who have both a scholarly interest in and professional commitment to physics teacher preparation. These leaders should be able to devote a major portion of their professional time to the teacher preparation effort. Such a leader or leadership team should be knowledgeable about the local K-12 school context and be able to influence the decision-making processes of the physics department. The leadership team could include a Master Teacher, i.e., a K-12 teacher with strong disciplinary knowledge and evidence of positive impact on student learning, or a scholar who has earned a doctorate in physics education research and who also has professional experience in K-12 teaching. The institution should support these leaders with adequate funding and other resources, and reward them with professional advancement. University presidents, provosts, deans, and department chairs should provide support so programs can flourish.

2. **Physics departments should recognize that they have a responsibility for the professional preparation of pre-service teachers.**

   a. Physics faculty should encourage students to consider teaching as a career option and ensure that interested students receive assistance in pursuing this goal. Physics faculty members advising future teachers should become informed about state requirements and university programs for obtaining certification to teach physics.

   b. Physics departments should develop a welcoming and encouraging environment that shows respect for the scholarship and practice of teaching. Physics faculty should encourage their best students to consider teaching and should promote teaching as an intellectually challenging endeavor. Teaching should be promoted as a legitimate career option on par with other options in research or industry.

"Physics faculty should encourage their best students to consider teaching and should promote teaching as an intellectually challenging endeavor."

   c. Physics departments that have made teacher preparation part of their mission should develop a rigorous track for future physics teachers that is informed by the state standards prescribing what has to be taught in high school physics. Physics departments should ensure that all the physics courses in the program for future physics teachers are both necessary and appropriate. The rigor of the track should be derived not only from the physics content but also from a sequence of courses that are focused on the teaching and learning of physics.

   d. Physics faculty should build a relationship with the education department faculty who are responsible for science teacher preparation and should assist students interested in teaching physics in contacting them.

3. **Schools of education should recognize that programs to prepare physics teachers must include pedagogical components specific to the preparation of physics teachers; broader "science education" courses are not sufficient for this purpose.**

a. To prepare future citizens to tackle 21st-century multi-disciplinary problems, teachers need a deep understanding of the content and pedagogy of specific disciplines. Teachers of physics need physics-specific pedagogical methods just as literacy teachers, bilingual teachers, and special education teachers need specialized pedagogical preparation in their disciplines.

"Teachers of physics need physics-specific pedagogical methods just as literacy teachers, bilingual teachers, and special education teachers need specialized pedagogical preparation in their disciplines."

b. Education faculty should seek physics-specific educational opportunities for future physics teachers just as they would for other education specializations. Course-related teaching placements and student teaching should be in physics classrooms under the supervision of specialists in physics education.

c. Education schools should ensure that all the education courses in the program for future physics teachers are both necessary and appropriate. The rigor of the track should be derived not only from the general pedagogical content but also from a sequence of courses that are focused on the teaching and learning of physics. Science education faculty should work closely with physics faculty to design and teach discipline-specific pedagogy courses for future physics teachers. Courses offered in the physics department that address pedagogical knowledge should be cross-listed by schools of education. These courses should be designed to meet state teaching certification requirements so that they can be used to fulfill part of students' education course requirements.

d. Education faculty should build a relationship with physics department faculty who work closely with future physics teachers, and should assist students interested in teaching physics in contacting them.

4. **Federal and private funding agencies, including the National Science Foundation and the U.S. Department of Education, should develop a coherent vision for discipline-specific teacher professional preparation and development.**

a. Within each funding agency, all programs related to teacher preparation and professional development should be coordinated by a single entity. This entity should implement a coherent vision for professional preparation and support of math and science teachers. Ultimately, these funding efforts should be coordinated across all public funding agencies.

b. Teacher preparation efforts form a coherent continuum that includes recruitment, pre-service education, induction, and professional development. All teacher-preparation funds provided by each funding agency should be made available for any of the individual phases of this process or for any well-integrated combination of phases.

c. Public and private funds targeted at teacher preparation and teacher professional development should be directed toward exemplary university-based programs as well as to such programs in K-12 schools, and K-12/University partnerships.

d. Both practicing STEM teachers who are new to teaching physics as well as prospective physics teachers should be eligible to receive funding sufficient to complete a high-quality program in physics teacher preparation.

e. Federal funding distributed through the states (e.g., block grants) that is currently targeted at short-term or non-discipline-specific professional development programs for science teachers should be redirected to coherent, extended programs that are focused on subject-specific pedagogy and teacher preparation (in physics, chemistry, earth and space science, et cetera).

5. **Professional societies should provide support, intellectual leadership, and a coherent vision for the joint work of disciplinary departments and schools of education in physics teacher preparation.**

a. Professional societies should advocate for the importance of physics teacher education within physics departments. They should stay abreast of and engage in the national discourse on educational policy, and should disseminate relevant policy documents. They should disseminate the results of research on physics teacher professional preparation and promote research-based practices.

b. Professional societies should facilitate discussion and collaboration among K-12 physics teachers, physicists, teacher educators, and physics education researchers aimed at improving physics education.

c. Professional societies should initiate new efforts and coordinate existing efforts designed to enhance STEM teacher education by engaging all stakeholders, including business, other disciplinary societies, private foundations, and other national organizations.

Quality

All components of physics teacher professional preparation programs should focus on improving student learning in the precollege physics classroom.

6. **Teaching in physics courses at all levels should be informed by findings published in the physics education research literature.**

   University physics instruction as well as K-12 physics instruction should take advantage of the extensive literature on student learning in physics and on research-validated instructional approaches. This will maximize student learning and will optimize the environment for students to consider teaching careers. Just as in scientific endeavors, in which physicists build on prior research, so too should programs to improve teaching be based on evidence of effectiveness and informed by results of research on how students learn physics. Information regarding research-based instructional programs is available at workshops conducted at national meetings of the American Association of Physics Teachers and the New Faculty Workshop in Physics and Astronomy. Physics education research literature is available in journals such as *Physical Review Special Topics-Physics Education Research* and the American Journal of Physics, which are accessible by physics faculty. Extensive archives of these materials are available at compadre.org. Physics faculty should become familiar with published reports on research-validated instruction and should be able to make evidence-based claims about the effectiveness of their own instruction.

7. **Physics teacher preparation programs should provide teacher candidates with extensive physics-specific pedagogical training and physics-specific clinical experiences.**

   a. Pre-service teachers benefit from expert mentorship as they learn to prepare and teach actual physics lessons. Thus, physics teacher preparation programs should include extended physics-specific teaching experiences along with physics-specific field placements for their certification candidates. Pre-service teachers also need specific instruction on how to teach various topics in physics. This instruction should be provided by physics master teachers, physics faculty, and/or physics education researchers.

   b. PTE programs should provide specific guidance to pre-service teachers on investigation-based physics instruction. For example, guidance should be provided on how to use motion detectors and force probes in investigations of force and motion. In order to provide such physics-specific mentoring and instruction, teacher preparation programs should draw on the expertise of existing faculty in physics and education departments, or commit to directing funds toward targeted faculty lines or full- or part-time master teachers.

   c. Every teacher preparation program should include at least one pedagogical course that focuses on the learning and teaching of various topics in physics. Such a course does not have to be exclusive to teacher education candidates but could be offered as an elective open to all physics majors, as well as non-degree or MA-seeking in-service teachers, while remaining a requirement for physics teacher certification candidates. Topics in such courses should include common student reasoning and thinking patterns in the various topics in physics, as well as effective methods for assessing student learning of these topics.

8. **Physics teacher education programs should work with school systems and state agencies to provide mentoring for early career teachers.**

   As junior faculty members are mentored in research groups, new teachers also need an opportunity to be mentored by veteran teachers and become a part of a community of scholars. Creating a professional learning community of physics teachers will reduce professional isolation and consequently should increase novice teacher retention. These communities should include both K-12 and university faculty and provide forums in which physics teachers can address instructional challenges, share lesson ideas, and continue to grow and develop professionally.

Recommendations 9(a) and 9(b) are intended to be implemented together to ensure that a higher standard for quality of preparation neither increases the length and cost of the program nor decreases the number of teachers who are qualified to teach more than one subject.

9(a). States should eliminate the general-science teacher certification and replace it with subject-specific endorsements.

General-science teacher certification provides flexibility to teach multiple subjects, which school administrators view as especially important in small and rural schools. However, general-science teaching certification ensures neither adequate knowledge of any particular content area, nor the pedagogical content knowledge needed for teaching a specific subject. By contrast, if teacher candidates obtain endorsements in two or more disciplines, they would be better prepared to teach each of these content areas so long as they also receive appropriate subject-specific pedagogical preparation and content background. Multiple endorsements would make it easier for teachers to accommodate the staffing needs of small schools. States should assess knowledge of subject-specific pedagogy as a required component of tests that are used to grant endorsement in a specific content area.

9(b). Higher education institutions should create pathways that allow prospective teachers to receive more than one endorsement without increasing the length of the degree.

Subject-specific endorsement programs should contain the appropriate subject matter preparation for teaching more than one discipline and appropriate preparation in the discipline-specific pedagogy of each of these subjects. This may require that new subject-specific pedagogy courses be added, and that they count toward the physics major and/or replace some of the education courses currently required for certification. These degree pathways will allow states to balance the often competing needs for greater numbers of qualified teachers who also have the broad preparation needed by small or rural school districts. Universities will need to take special care to ensure that the expected length of study—and hence the financial impact on the teacher—does not increase when endorsement in multiple disciplines is substituted for general-science certification.

10. National accreditation organizations should revise their criteria to better connect accreditation with evidence of candidates' subject-specific pedagogical knowledge and skill.

Accreditation should require evidence of substantial oversight of physics teaching experiences by physics content experts, and of the required completion of subject-specific pedagogy courses in the certification program. The accreditation process should also require evidence of candidates' skills in synthesizing and using their knowledge to elicit, interpret, assess, and address students' ideas about specific, important physics topics with appropriate instructional interventions. Accreditation evidence should include candidates' knowledge and skills as they relate to helping students master specific physics concepts (e.g., the nature of force) and specific physics process skills such as collecting, analyzing, graphing, and modeling data.

11. Physics education researchers should establish a coordinated research agenda to identify and address key questions related to physics teaching quality and effective physics teacher preparation.

Physics education researchers have developed preliminary measures of student conceptual understanding and student learning, and have investigated a multitude of factors that have significant influence on student achievement in physics. To date, however, most of this work has been confined to post-secondary education. Analogous work is needed in the K-12 context. A handful of research efforts are just beginning to explore the relationships among physics student achievement, teacher attributes and behaviors, learning environments, curriculum, and instructional practices. This important work should be expanded into large-scale coordinated research programs both to respond to current national needs and to lay the basis for rigorous evaluation of future efforts in physics teacher education.

Capacity

The United States should take significant steps to alleviate the severe shortage of qualified physics teachers.

12. Physics departments and schools of education should design certification pathways for individuals in various populations to become well-prepared physics teachers: undergraduate students who have not yet chosen a major, undergraduate STEM majors, graduate students in STEM disciplines, STEM teachers who may not yet be prepared to teach physics, and STEM professionals such as engineers, scientists, and laboratory technicians.

a. Active recruitment of STEM students into physics teaching is necessary to increase the number of physics teachers. The recruiting pool should be broad and include undergraduates as well as graduate students, physics majors as well as other STEM majors who have sufficient physics background or can acquire it.

b. Teacher preparation programs should have streamlined pathways for STEM research professionals as well as for experienced STEM teachers, respecting and capitalizing on the different experiences of each of these groups. While STEM professionals and experienced STEM teachers both require high-quality instruction in physics content along with physics-specific pedagogical education, the physics teacher endorsement program should not require an extensive amount of time to complete and should be designed to accommodate the special scheduling constraints of these professionals.

c. Special pathways for STEM professionals and experienced STEM teachers will have significant intersections with pathways designed for undergraduate teacher preparation. To promote interaction and discussion among diverse student groups and to increase enrollment in courses on physics-specific pedagogy, these courses should be structured to simultaneously enroll undergraduate STEM majors, in-service STEM teachers, and post-baccalaureate STEM professionals.

A National Proposal: Regional Centers in Physics Education

The T-TEP recommendations address crucial issues associated with individual institutions and programs. However, an effective and coordinated national strategy in physics teacher education must go beyond individual implementation of the aforementioned recommendations. An innovative national program is needed both to use all resources currently available, and to develop new resources, expertise, and capacity in order to meet current and future national needs. Toward this end, T-TEP recommends the establishment of regional centers in physics education.

A regional center would serve the need for new teachers in its greater geographical area while also providing support to in-service teachers and addressing state and national issues in teacher education. Regional centers are needed because educational policies and regulations vary from state to state, and teachers tend not to go far from the institution from which they graduated.

a. Regional centers would pool expertise in the research and practice of physics teacher education, create vibrant communities of prospective and practicing physics teachers, and be the home of regional physics teacher preparation and scholarly work on K-20 physics education. Such scholarship would include research on teacher preparation, investigation and assessment of student learning, development of instruments to assess teacher attributes and impacts, program evaluation, and development of educational policy.

b. Regional centers could take multiple forms; for example, they could be based at one institution or be a collaboration among multiple neighboring institutions. Colleges, universities, two-year colleges, and school districts throughout the region could serve as feeders to the regional center, and articulation agreements could help ensure an efficient, high-quality pathway for students earning a physics degree, physics teaching endorsement, or both. A possible model is the "three-two" engineering program, in which a student spends three years at a liberal arts institution and finishes the last two years a technical institution, earning degrees both in engineering and a STEM discipline. Another possible model is a post-baccalaureate program in physics teaching offered at the regional center; nearby institutions could send their graduates, and such a program would serve the needs of career changers as well.

c. The size, diversity, and resources of regional centers would enable them to serve all three major populations of prospective physics teachers: undergraduate students, practicing teachers with weak physics backgrounds, and career-changing STEM professionals who typically opt for alternative certification programs. Regional centers also could have the potential to attract groups that are traditionally underrepresented in physics, including women and minorities. The availability of effective mentoring in the context of diverse and regionally based student populations at these centers would tend to improve recruitment and retention of underrepresented groups. These students would have access to an array of pooled resources that are more likely to address a greater diversity of needs.

d. Regional centers could be funded internally by colleges and universities and externally by federal and state agencies and private foundations. The federal government currently spends billions of dollars on STEM education; regional centers could be funded by reallocating a small fraction of the funds spent on teacher professional development programs, many of which lack evidence of effectiveness. In addition to funding needed for program faculty and staff, financial support would probably be needed for teachers and teacher candidates to enable them to take short leaves from their jobs or schools. (An example of such funding is the NSF Noyce Scholarship program.) Regional centers could support students and, at the same time, help serve local communities by assigning internships for pre-service teachers in local middle and high schools.

e. Regional centers for the education of physics teachers could serve as models for discipline-based preparation and professional development of other STEM teachers.

Foundational Material I: Historical Context of U.S. Physics Teacher Education

David E. Meltzer, lead author

Introduction

In the process of reviewing hundreds of reports, research papers, and policy statements regarding the education of physics teachers all over the world—extending from the 1880s and continuing up to the current year—we were struck by the consistency and reproducibility of the findings and recommendations of the various committees, professional organizations, and independent researchers.[1] Our recommendations, as detailed in Chapter 4, are consistent therefore not only with the specific findings of our own investigation, but also with the vast body of research and analysis generated by others who have examined these same problems during the past 130 years. In this Section we will provide a summary of the key findings and major recommendations regarding teacher education in physics that have been generated in the United States during this period. We will weave into the discussion some of T-TEP's findings and recommendations, so that they may be seen within the perspective of the broader history of work in this field.

"The issues regarding physics teacher education that we address in this Report are not new, and ours is not the first investigation that has described the problems and made recommendations for improvement."

Overview: The Shortage of Qualified Physics Teachers

The issues regarding physics teacher education that we address in this Report are not new, and ours is not the first investigation that has described the problems and made recommendations for improvement. In our Executive Summary, we note:

> Over the past 20 years, academic, business, and governmental leaders have warned that United States science education needs a dramatic overhaul.…
>
> ...the preparation of qualified physics teachers has failed to keep pace with a dramatic increase in the number of high-school students taking physics. Consequently, more students than ever before are taking physics from teachers who are inadequately prepared.
>
> The potential negative consequences of maintaining the status quo are far-reaching, both for physics as a discipline and for the U.S. economy and society as a whole....
>
> ...Most physics teachers have no substantial formal training in either physics or physics teaching. Instead, they develop their skills through on-the-job practice, without expert mentoring, teaching a subject that they never originally intended nor were trained to teach.

In fact, from the earliest days of wide-scale high school physics teaching in the United States in the late 1800s, physics educators have noted and bemoaned a shortage of qualified physics teachers. Ironically, their observations were sometimes accompanied by overoptimistic projections of future improvements in supply.[2] One of the origins of this oft-noted shortage was that, before 1910, more than 90% of U.S. high schools were located in cities having populations under 8,000. Although most U.S. high school students attended these schools, they were quite small, with an average of around three teachers per school, and thus were in no position to hire specialist teachers of physics.[3] The prevalence of small schools persisted well into the 20th century and, along with limited physics enrollments, helped ensure that over 80% of U.S. secondary school physics teachers in 1961 spent the majority of their time teaching subjects other than physics.[4] This problem was aggravated by the persistence of the long-standing

1. For lists of references see "Resources for the Education of Physics Teachers" in this Report as well as David E. Meltzer, "Research on the education of physics teachers," in *Physics Teacher Education: Research, Curriculum, and Practice*, edited by David E. Meltzer and Peter S. Shaffer (American Physical Society, College Park, MD, 2011), pp. 3-14.

2. Frank Wigglesworth Clarke, *A Report on the Teaching of Chemistry and Physics in the United States* [Circulars of Information of the Bureau of Education, No. 6–1880] (Government Printing Office, Washington, 1881), p. 11; p. 19; Charles K. Wead, *Aims and Methods of the Teaching of Physics* [Circulars of Information of the Bureau of Education, No. 7–1884] (Government Printing Office, Washington, 1884), p. 125.

3. C. Riborg Mann, *The Teaching of Physics for Purposes of General Education* (McMillan, New York, 1912), pp. 19-21.

4. National Association of State Directors of Teacher Education and Certification and the American Association for the Advancement of Science [William P. Vial, Director of the Survey], *Secondary School Science and Mathematics Teachers: Characteristics and Service Loads* [NSF 63-10] (National Science Foundation, Washington, D.C., 1963), ERIC Document 030573, p. 6.

U.S. tradition to teach physics only as (or primarily as) a single-year high school course with little or no focused physics instruction in earlier grades. The U.S. is one of few developed countries to follow this practice, which was initiated in the 1800s and institutionalized in the first decades of the 20th century.[5] Even this single physics course has been populated in recent years only by a small minority of all high school students. The fraction of U.S. high school graduates who had taken a physics course climbed back above 30% in the public schools only within the past decade—a level not previously seen since around the late 1920s.[6] Consequently, as late as 1987, 76% of high school physics teachers surveyed by AIP reported having only one or two physics classes in their teaching assignment, and less than a quarter had their primary concentration of classes in physics.[7]

With such a limited demand for specialist instructors, it is not surprising that there have never been more than a handful of dedicated programs to train qualified physics teachers in the U.S. Although the shortage of qualified high school physics teachers has long been considered to be a "critical" problem in the U.S. and various remedies have been proposed, little effective action has been taken to address the evident practical challenges involved in improving the situation.[8] Nonetheless, essentially every report regarding science teacher education in the United States over the past century, with various degrees of urgency, has labeled the supply of physical science teachers as inadequate.[9]

"...essentially every report regarding science teacher education in the United States over the past century, with various degrees of urgency, has labeled the supply of physical science teachers as inadequate."

The Education of Physics Teachers 1909-1932

In 1899, Prof. Edwin Hall of Harvard chaired the physics subcommittee of the Committee on College Entrance Requirements established by the National Educational Association. Through this and related activities Hall and numerous other university physicists of that era were deeply engaged in issues related to secondary school physics teaching. In 1909, Hall reported on a meeting of a group of physicists in which general recommendations regarding the education of high school physics teachers were adopted. These recommendations implied the desirability of preparation at the level of a graduate student in physics.[10]

In 1920, George Twiss of Ohio State University chaired the physics subcommittee of the Commission on the Reorganization of Secondary Education, appointed by the National Education Association. Twiss wrote that "…prospective [science] teachers must be trained in a very different way

5. Keith Sheppard and Dennis M. Robbins, "The 'First Physics First' movement, 1880-1920," *The Physics Teacher* **47**, 46-50 (2009); David E. Meltzer, "Research on the education of physics teachers." Robert Millikan was sharply critical of this practice; see R. A. Millikan, "Science in the secondary schools," *School Science and Mathematics* **17**, 379-387 (1917).
6. See Figure 1 in Susan White and Casey Langer Tesfaye, *High School Physics Courses & Enrollments: Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010), p. 1; available at: http://www.aip.org/statistics/trends/reports/highschool3.pdf. In the late 1800s, before the elective system was introduced, physics was taken by about 95% of all students graduating from high school (and about 23% of all students at any one time). However, at that time, those students represented only about 5% of their age cohort in the population; see, e.g., W. C. Kelly, "Physics in the public high schools," *Physics Today* **8**(3), 12-14 (1955). Moreover, most of those students took physics not from qualified physics teachers but, instead, from one of the three or four generalist teachers who made up the entire faculty of the typical high school at that time. The elective system that was introduced around 1900 resulted in a dramatic and long-lasting decline in the proportion of high school graduates who took physics, sinking to around 20% and not changing much for almost a century, until the recent explosion of enrollment in conceptual physics courses that began around 20 years ago.
7. Michael Neuschatz and Maude Covalt, *Physics in the High Schools: 1986-1987 Nationwide Survey of Secondary School Teachers of Physics* (American Institute of Physics, New York, 1988), p. 5. The extent to which U.S. physics teachers have focused their actual teaching time on physics has undergone a slow though continuous evolution, but survey ambiguities make it difficult to provide precise numbers. In 1969, about 40% of secondary-school physics teachers surveyed said that physics was their "major" teaching assignment; see Vitro Laboratories, *Secondary School Science Teachers, 1969: Background and Professional Characteristics* [Educational Research and Evaluation Project of Vitro Laboratories; Martin Hershkowitz, Project Manager] (Division of Science Resources Studies, National Science Foundation, Washington, D.C., 1971), p. 98; also see Physics Survey Committee, National Research Council, *Physics in Perspective, Volume I* (National Academy of Sciences, Washington, D.C., 1972), pp. 747-748. However, as noted above, less than 25% of high school physics teachers surveyed by AIP in 1987 had their primary concentration of classes in physics, a figure that did not reach 41% until 2001 and did not exceed 50% until 2009; See: Susan White and Casey Langer Tesfaye, *Who Teaches High School Physics? Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, College Park, MD, 2010), p. 3; available at: http://www.aip.org/statistics/trends/reports/hsteachers.pdf.
8. Arnold A. Strassenburg, "American Institute of Physics programs in education—present and future," *American Journal of Physics* **35**, 797-807 (1967).
9. An extensive bibliography of such reports in this Report is contained in Resources for the Education of Physics Teachers on page 82.
10. Edwin H. Hall, "The relations of colleges to secondary schools in respect to physics," *Science* **30**, 577-586 (1909).

from that in which most of them are now being trained." These teachers would need "to approach all their teaching problems inductively, and to study their pupils and their pupils' interests and needs, no less than they study the subjects which they are to teach." To ensure that universities would be in a position to offer this type of training, Twiss recommended that

> These prospective teachers should also be brought under the influence of a type of professor that should be represented in every large university [science] department, namely, one whose chief interest is in the teaching side of the subject, a master not only of the subject itself but also of its pedagogy in the schools, a skilled teacher of the subject, and also an inspiring teacher of teachers. He should not forego research, but his research should be in the field of the applied psychology and sociology of his science.[11]

In 1932, the Committee on the Teaching of Science of the National Society for the Study of Education published their influential 31st Yearbook, Part I of which was devoted to "A Program for Teaching Science." They noted that many courses offered to prospective teachers were "given as short-cuts to success" and, in the case of one course for physics teachers, they pointed out that "It is clear that the instructor in charge of this course is attempting in his one-term course to make high-school teachers of physics out of students who have no larger background of training than that which comes from the study of physics in high school. This illustration is not an isolated case."[12] In regard to this practice, the Committee cited a study which found that "pupils who were taught by teachers who had majored in college physics excelled in average achievement the pupils who were taught by teachers who had not majored in college physics. The superiority was evident on every test." The Committee went on to state,

> This investigation seems to present clear evidence that pupils in physics classes are handicapped in their achievement when their teachers lack a thoroughly adequate background of subject matter.…This Committee, therefore, unqualifiedly condemns the practice, wherever it may exist, of assigning any science course to a teacher who is not adequately prepared in the subject matter of that course.[13]

11. George R. Twiss, "The reorganization of high school science," *School Science and Mathematics* **20**, 1-13 (1920).
12. Guy Montrose Whipple, editor. *The Thirty-First Yearbook of the National Society for the Study of Education, Part I: A Program for Teaching Science*, prepared by the Society's Committee on the Teaching of Science [Gerald S. Craig, Elliot R. Downing, Charles J. Pieper, Ralph K. Watkins, Francis D. Curtis, and S. Ralph Powers] (Public School Publishing Company, Bloomington, IL, 1932), p. 329.
13. *Ibid.*, pp. 80-81.

1939-1960

In 1939, the American Association of Physics Teachers (AAPT) established a "Committee on the Teaching of Physics in Secondary Schools." In 1940, this committee initiated contacts with other scientific societies to form a cooperative group specifically focused on improving science teaching and the education of science teachers,[14] and in 1946, the Committee issued a report to address "a deficiency in the number of well-trained science teachers in the secondary schools." In this report the Committee noted

> …the desirability of cooperation between science departments, on the one hand, and the education departments, on the other, in the college program of training secondary school teachers of science….
>
> *...the committee definitely suggests such line of action to college teachers of physics….*
>
> *…joint participation in the supervision of practice teaching by subject matter departments and the department of education can work to the great advantage of teachers-in-preparation.*[15] [Emphasis in original.]

Another issue associated with the limited demand for specialist science teachers had been addressed by the "Cooperative Committee on Science Teaching," the joint organization of mathematics and science societies formed in 1941 at the initiative of the AAPT's Committee on the Teaching of Physics in Secondary Schools. The Cooperative Committee recognized as serious the

> ...problem of combinations of subjects to be taught by the beginning teacher in the small school….Most teachers begin their work in small secondary schools of 200 or fewer students, where one must teach three or four different subjects. Therefore, a college graduate with highly specialized training in a single science is at a disadvantage in securing a position and in his teaching if he is appointed.[16]

Although today's context is somewhat different, this issue persists and has been addressed (see Chap. 4 of this Report) in T-TEP Recommendation 9(b):

14. K. Lark-Horovitz, "Report of the Committee on the Teaching of Physics in Secondary Schools," *American Journal of Physics* **10**, 60-61 (1942). The cooperative group was formed in 1941 and called "The Cooperative Committee on Science Teaching"; see Glen W. Warner, "The Cooperative Committee on Science Teaching," *American Journal of Physics* **10**, 121-122 (1942).
15. K. Lark-Horovitz et al., "Responsibilities of science departments in the preparation of teachers: A report of the Committee on the Teaching of Physics in Secondary Schools," *American Journal of Physics* **14**, 114-115 (1946).
16. Glen W. Warner, "The Cooperative Committee on Science Teaching."

9(b). Higher education institutions should create pathways that allow prospective teachers to receive more than one endorsement without increasing the length of the degree.

Subject-specific endorsement programs should contain the appropriate subject matter preparation for teaching more than one discipline and appropriate preparation in the discipline-specific pedagogy of each of these subjects….These degree pathways will allow states to balance the often competing needs for greater numbers of qualified teachers who also have the broad preparation needed by small or rural school districts.

In 1956, a joint commission was formed by the American Association for the Advancement of Science and the American Association of Colleges for Teacher Education. This "Joint Commission on the Education of Teachers of Science and Mathematics" made the following explicit recommendation in 1960:

Scientists should recognize, and persuade their students to recognize, that public school teaching is an important and challenging profession which merits consideration by persons of first-rate ability….

Each institution preparing science teachers should create a committee of scientists, science teachers, and professional educators to give attention to the development of science teacher education programs.[17]

These statements are fully consistent with T-TEP's recommendations (see Chap. 4 of this Report):

Physics faculty should encourage students to consider teaching as a career option and ensure that interested students receive assistance in pursuing this goal. (2a)

Physics faculty should encourage their best students to consider teaching and should promote teaching as an intellectually challenging endeavor. (2b)

Physics faculty should build a relationship with the education department faculty who are responsible for science teacher preparation and should assist students interested in teaching physics in contacting them. (2d)

Pre-service teachers benefit from expert mentorship as they learn to prepare and teach actual physics lessons. Thus, physics teacher preparation programs should include extended physics-specific teaching experiences along with physics-specific field placements for their certification candidates. Pre-service teachers also need specific instruction on how to teach various topics in physics. This instruction should be provided by physics master teachers, physics faculty, and/or physics education researchers. (7a)

Beginning in the late 1940s, as a partial amelioration of the shortage of qualified teachers, universities and private companies established summer enrichment programs for in-service physics teachers, as well as for teachers of mathematics and other science fields. After the Soviet Union launched Sputnik in 1957, the number of these institutes expanded dramatically at the insistence of the U.S. Congress, with funding provided by the National Science Foundation.[18]

"Beginning in the late 1940s, as a partial amelioration of the shortage of qualified teachers, universities and private companies established summer enrichment programs for in-service physics teachers...."

1961-1973

In 1966, the Physics Survey Committee of the National Academy of Sciences (NAS) linked a "severe educational crisis for physics" in the high schools to a shortage of competent high school physics teachers.[19] A later physics survey by the NAS underlined the inadequacies of science teacher education and strongly emphasized the critical role college and university physics departments played in educating both prospective and practicing science teachers.[20] The American Institute of Physics (AIP) instituted a variety of programs during the 1960s to attempt to remedy

17. Joint Commission on the Education of Teachers of Science and Mathematics, *Improving Science and Mathematics Programs in American Schools* (American Association for the Advancement of Science and American Association of Colleges for Teacher Education, Washington, D.C., 1960), p. 40.

18. Hillier Krieghbaum and Hugh Rawson, *An Investment in Knowledge: The First Dozen Years of the National Science Foundation's Summer Institutes Programs to Improve Secondary School Science and Mathematics Teaching, 1954-1965* (New York University Press, New York, 1969).

19. Physics Survey Committee, National Academy of Sciences, *Physics: Survey and Outlook* [A report on the present state of U.S. physics and its requirements for future growth] (National Academy of Sciences, National Research Council, Washington, D.C., 1966), p. 30.

20. Physics Survey Committee, National Research Council, *Physics in Perspective, Volume I* (National Academy of Sciences, Washington, D.C., 1972), pp. 27-30.

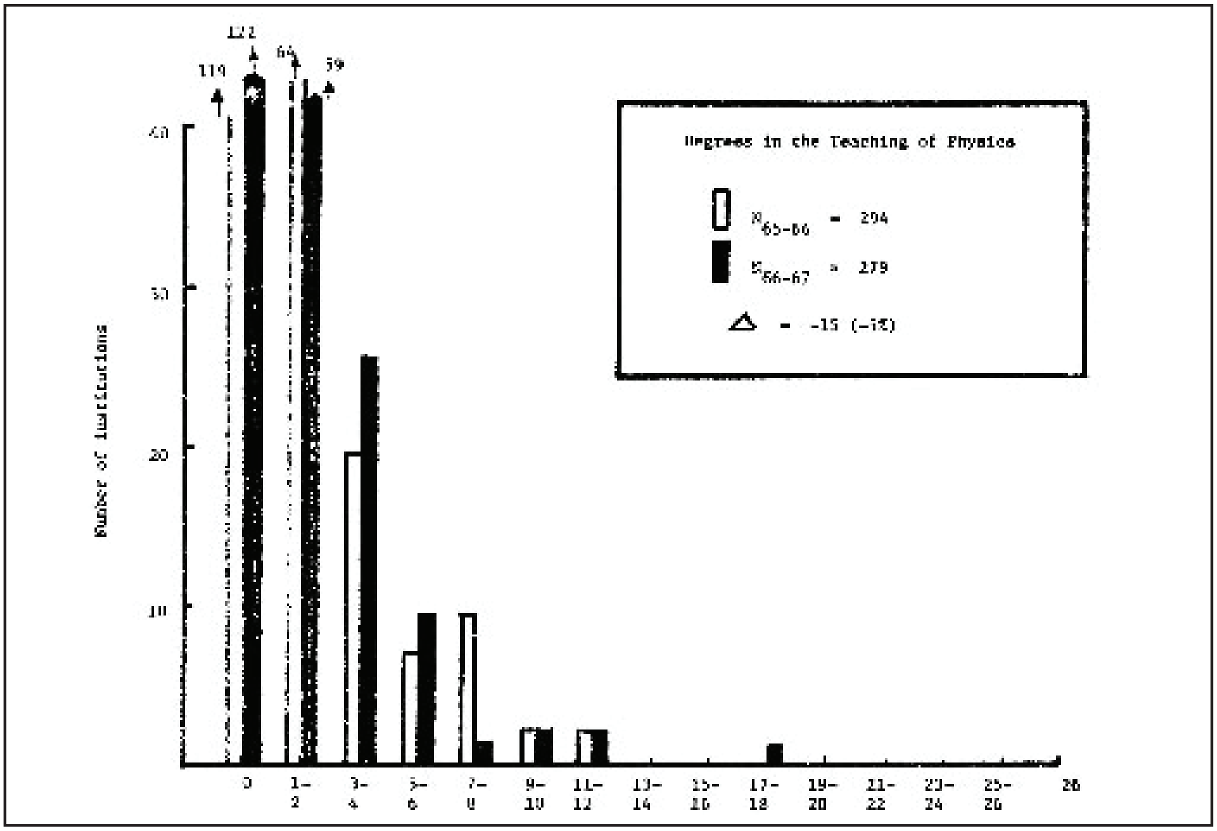

Figure 8. Distribution of physics teacher graduates from U.S. institutions, 1965-1967. Source: See Ref. 26 on p. 34.

the shortage of qualified physics teachers.[21] In 1960, the top leadership of both the AIP and the American Association of Physics Teachers (AAPT) joined to form the Commission on College Physics (CCP), an organization of physics educators whose creation was supported by a grant from the National Science Foundation. The declared purpose of the Commission was to improve the teaching of physics at the college level, but its interests extended to issues related to physics teaching in the high schools.

In 1966, the CCP established the "Panel on the Preparation of Physics Teachers" (PPPT). On behalf of the Commission, the PPPT carried out an extensive investigation of the preparation of high school physics teachers and published a detailed report in 1968 with a second, updated edition published in 1972.[22] An entire session at the 1969 Summer Meeting of the American Association of Physics Teachers was devoted to reports and discussion on the recruitment and preparation of physics teachers, presented by members of the Commission.[23]

The Commission stated its conclusions bluntly:

> Most of our present high school physics teachers are unprepared to teach physics.…
>
> The critical factor is the low rate of supply of well-prepared new teachers….This shortage has led the National Education Association to designate physics as a "critical" subject area.…
>
> ...It is our continuing failure to provide anything like enough trained high school physics teachers that causes high schools to draft others for the job….[24]

21. Strassenburg, "American Institute of Physics programs in education—present and future."
22. (a) Commission on College Physics, *Preparing High School Physics Teachers* [Report of the Panel on the Preparation of Physics Teachers of the Commission on College Physics, Ben A. Green, Jr., et al.] (Department of Physics and Astronomy, University of Maryland, College Park, MD, 1968), ERIC Document ED029775; (b) Commission on College Physics, *Preparing High School Physics Teachers II* [revised edition] [University of Maryland, College Park, MD, 1972].
23. The invited papers from that session may be found in *Commission on College Physics Newsletter*, Number 20 (College Park, MD, 1969), ERIC Document ED045336.
24. Commission on College Physics, *Preparing High School Physics Teachers* (1968), p. 5.

The Commission asserted that "the shortage of qualified high school physics teachers is one of the most pressing problems facing American physics today," and asked:

> What are academic physics departments doing to remedy this situation? For the most part, very little.…
>
> ...Well-known, high-prestige departments rarely have programs specifically tailored to the needs of the prospective high school physics teacher….
>
> ...These same departments typically graduate two or three teachers *every five years.*
>
> ...Less than ten of the schools surveyed graduate more than five physics teachers per year.... [Emphasis in original.] [25]

More than 40 years later, T-TEP finds that this situation has not changed *at all*. A bar chart demonstrating the highly skewed distribution of physics-teacher graduates from U.S. institutions—most institutions graduating zero or one per year, a tiny handful graduating more than four—can be found in a survey of science teacher education programs carried out in the mid-1960s (see Figure 8).[26] The analogous chart resulting from our own findings is essentially identical to this one.[27]

The Commission stated that "it is clear that more physics departments should assume the responsibility of providing adequate training to prospective secondary school science teachers, especially prospective physics teachers."[28] This may be compared to Recommendation #2:

> **2. Physics departments should recognize that they have a responsibility for the professional preparation of pre-service teachers.**
>
> Physics departments that have made teacher preparation part of their mission should develop a rigorous track for future physics teachers that is informed by the state standards prescribing what has to be taught in high school physics….The rigor of the track should be derived not only from the physics content but also from a sequence of courses that are focused on the teaching and learning of physics. (2c)

A member of the committee that prepared the updated 1972 Commission report noted that, with respect to colleges and universities having physics teacher preparation programs, "The number of prospective physics teachers showed no correlation with the size of the institution; it depended almost invariably upon the amount of interest and concern actively expressed by one or more physics staff members at their institution."[29] T-TEP has reproduced this remarkable observation. Our major finding of the present-day indispensability of a program champion is completely consistent with the situation in the 1960s:

> **Without exception, all of the most active physics teacher education programs have a champion who is personally committed to physics teacher education. With few notable exceptions, these program leaders have little institutional support.**[30] [Finding #2]

In recognition of the particular needs of future teachers, the Commission on College Physics strongly advocated that universities create physics courses specifically designed for prospective physics teachers, incorporating active participation in both learning and teaching as well as more exposure to physics classroom situations.[31] Such courses have long been accepted and implemented in many other countries as necessities for an effective physics teacher preparation program. Similarly, in other countries it is common for university-based teacher education programs to be led or assisted by physics education specialists with extensive school teaching experience.[32] T-TEP has explicitly recommended that teacher education programs incorporate a sequence of courses focused on the teaching and learning of physics, including (as noted above) physics-specific teaching experiences supervised by physics educators. We also recommend that experienced high school physics teachers be involved in mentoring and supervising prospective physics teachers, as specified in Recommendation #7:[33]

> …physics teacher preparation programs should include extended physics-specific teaching experiences.… Pre-service teachers also need specific instruction on how to teach various topics in physics. This instruction should be provided by physics master teachers, physics faculty, and/or physics education researchers. (7a)

25. *Ibid*.
26. David E. Newton and Fletcher G. Watson, *The Research on Science Education Survey: The Status of Teacher Education Programs in the Sciences, 1965-1967* (Harvard Graduate School of Education, Cambridge, MA, 1968), p. 26, Figure 1.
27. See this Report, Chapter 3, "Findings," Figure 6.
28. Commission on College Physics, *Preparing High School Physics Teachers II* (1972), p. 9.
29. S. Winston Cram, as quoted in John L. Lewis, editor, *Teaching School Physics* [A UNESCO Source Book] (Penguin, Harmondsworth, England, 1972), p. 272.
30. See Chap. 3 of this Report.
31. Commission on College Physics, *Preparing High School Physics Teachers* (1968), p. 7-8; Commission on College Physics, *Preparing High School Physics Teachers II* (1972), pp. 9-15.
32. Meltzer, "Research on the education of physics teachers."
33. See Chap. 4 of this Report.

> Every teacher preparation program should include at least one pedagogical course that focuses on the learning and teaching of various topics in physics.…Topics in such courses should include common student reasoning and thinking patterns in the various topics in physics, as well as effective methods for assessing student learning of these topics. (7c)

Physics educators have long recognized the importance of ongoing education and mentorship for physics teachers after they have graduated and begun their teaching career. For example, the Commission on College Physics advocated that physics departments, besides offering formal courses, entertain other approaches that could include:

> …workshops or symposia, informal associations on a regional basis, consulting arrangements, resource sharing and others. The increased communications gained through such efforts would be a significant step in the recognition of high school physics teachers as colleagues of the college and university physics faculties.[34]

The Physics Survey Committee of the National Academy of Sciences made similar recommendations in 1973. This Committee asserted that "practicing teachers must have continuing, convenient access to the latest curricular materials and established pedagogical techniques." Consequently, they said, institutions that prepare teachers should take an active role in providing workshops, seminars, intensive summer programs, and other resources for practicing physics teachers.[35] These ideas are reflected in Recommendation #8:

> **8. Physics teacher education programs should work with school systems and state agencies to provide mentoring for early career teachers.**
>
> As junior faculty members are mentored in research groups, new teachers also need an opportunity to be mentored by veteran teachers and become a part of a community of scholars….These communities should include both K-12 and university faculty and provide forums in which physics teachers can address instructional challenges, share lesson ideas, and continue to grow and develop professionally.

34. Commission on College Physics, *Preparing High School Physics Teachers II* (1972), p. 15.
35. Physics Survey Committee, National Research Council, *Physics in Perspective, Volume II, Part B, The Interfaces* (National Academy of Sciences, Washington, D.C., 1973), p. 1220 (Section XIII, "Education"), Chap. 9, "The institutions of physics education."

The Nature of Physics Education

In 1973, the Physics Survey Committee of the National Academy of Sciences (NAS) explicitly addressed the specific nature of the physics courses that would best prepare future science teachers:

> Science should be taught in the schools….in a manner that encourages inquiry by the child, independent and self-paced, but guided….
>
> Successful use of inquiry-directed instruction requires teachers who have themselves learned to investigate in this manner. At present, the education of teachers is very weak in this respect. A broad and intensive effort is needed to give prospective and in-service teachers the background for leading pupils into independent inquiry….
>
> We advocate widespread introduction of courses conducted in the inquiry mode and intended for elementary and secondary school teachers.…Physics faculty members should seek the cooperation of the education faculty to encourage the population of these courses. They should also acquaint themselves with developmentsin the psychology of learning.…[36]

"'We also must teach…[high school teachers] in the manner we hope they will subsequently use in their own classrooms.'"

> A fair question is whether, through courses of any kind, teachers can be induced to improve their understanding of science and alter their performance. Results of studies are beginning to appear, suggesting that significant changes in teaching performance occur after the teacher has been in an inquiry-centered course.…[37]
>
> The general principles enunciated above [for teaching physics to elementary school teachers]…apply equally well to the preparation of high school teachers. We also must teach them in the manner we hope they will subsequently use in their own classrooms.[38]

36. *Ibid.*, pp. 1145-1146 (Section XIII, "Education"), Chap. 1, "Recommendations."
37. *Ibid.*, p. 1175 (Section XIII, "Education"), Chap. 4, "Teaching the teachers of science."
38. *Ibid.*, p. 1179.

The report of the Commission on College Physics (CCP) discussed some features of the pedagogical methods referred to by the NAS Physics Survey Committee:

> Courses could, for instance, be developed which try to adapt to college use the "learning by discovery" method now so widely used in the schools. This type of course leads a student to puzzle things through for himself, offering both the experience of being a scientist and the satisfaction that accompanies success. Furthermore, it might provide a model for teaching high school physics since teachers generally teach as they are taught.[39]

An appendix to the CCP report describes these methods in more detail, emphasizing having students focus on systems exhibiting "interesting physical phenomena." The student:

> …should be encouraged to make models of how the system under investigation behaves, and to design tests which will check the validity of the models….the instructor should guide the students to devise methods of seeking answers to their own questions….
>
> ...students…would be intimately involved in the processes of observation and reasoning.[40]

This emphasis on "learning by discovery," on physics instruction that is "inquiry-directed" and which stresses student investigations, far from being a new development of the 1960s, can be traced back directly to analogous emphases on learning through "inductive" methods that had been widely supported by physics educators back in the 1880s and frequently reemphasized up through the 1920s.[41]

Over forty years of further research and development have brought such "active-learning" pedagogical methods in physics to a high level of effectiveness.[42] Many researchers have subsequently reiterated and re-emphasized the broad utility of this approach in physics teacher education, as reflected in numerous reports and references cited in our Resources for the Education of Physics Teachers, and discussed further in the section of this Report entitled "Foundational Material II: Research on Physics Teacher Education" (pp. 37-39). In recognition of these findings, Recommendation #6 implies that it is not sufficient for prospective teachers of physics to be exposed only to traditionally taught lecture courses, but that they must also benefit from the many advances in research-based physics instruction developed over the past 40 years:

> **6. Teaching in physics courses at all levels should be informed by findings published in the physics education research literature.**
>
> University physics instruction as well as K-12 physics instruction should take advantage of the extensive literature on student learning in physics and on research-validated instructional approaches. This will maximize student learning and will optimize the environment for students to consider teaching careers.… Physics faculty should become familiar with published reports on research-validated instruction and should be able to make evidence-based claims about the effectiveness of their own instruction.

Summary

It is ironic that for much of the past century, the United States has been a world leader in science and technology—and in physics in particular—*despite* the lack of an effective system for educating physics teachers. As the foregoing discussion makes clear, such a system has never existed in the U.S. One can reasonably ask whether it is really so urgent for the educational system to change if, as it seems, inadequate physics teacher education has not prevented the U.S. from assuming a leadership role on the world science stage. However, times are changing, and a multitude of reports—exemplified by those cited in Chapter 1 of this Report—suggest that the pace of such change has accelerated during the past 20 years. As our discussion in Chapter 1 makes clear, there is abundant and growing evidence that the imperfect public educational system in physics and other sciences has evolved from being, arguably, merely a hindrance to scientific and technological development, into what is now a potentially insuperable obstacle standing in the way of continued U.S. preeminence in science and technology.

39. Commission on College Physics, *Preparing High School Physics Teachers* (1968), p. 12.
40. Appendix C, Arnold A. Strassenburg, "A discovery approach to introductory physics," in Commission on College Physics, *Preparing High School Physics Teachers* (1968), pp. 20-21.
41. See, e.g., Wead, *Aims and Methods of the Teaching of Physics*, pp.117-122, and Twiss, "The reorganization of high school science."
42. David E. Meltzer and Ronald K. Thornton, "Resource Letter ALIP–1: Active-Learning Instruction in Physics," *American Journal of Physics* **80**, 478-496 (2012).

Foundational Material II: Research on Physics Teacher Education

David E. Meltzer, lead author

Overview

Relatively few published research studies have addressed the impacts of U.S. physics teacher education programs. However, several recent investigations have probed the outcomes of programs in which there is a strong focus on physics-specific pedagogy using research-validated instructional methods of the type recommended in this Report.[1]

An unusual and revealing investigation was commissioned by the National Science Foundation (NSF) and carried out by the TIMSS International Study Center at Boston College.[2] In this study, the TIMSS twelfth-grade physics test was administered to a random sample of twelfth-grade students taught by teachers who had participated in NSF-sponsored teacher enhancement and materials development programs. These NSF-sponsored programs included several that were based on research in physics education and that used instructional methods described and endorsed in this report. The study revealed that students taught by teachers who had participated in the NSF-sponsored programs significantly outperformed other U.S. high school physics students who had taken the same test.[3]

"...students taught by teachers who had participated in the NSF-sponsored programs significantly outperformed other U.S. high school physics students who had taken the same test."

A number of other studies reported in peer-reviewed journals and proceedings have examined outcomes from individual university-based teacher education programs. In the remainder of this section we will review and briefly summarize several of these studies; detailed reports may be found in the cited references.

Research on Programs for Prospective and Practicing Teachers

Pre-service teachers in the University of Washington's *Physics by Inquiry* program taught lessons on light in a ninth-grade classroom using materials and methods they had themselves recently learned. Their ninth-grade students had much higher scores (45%) on post-instruction diagnostic tests than did undergraduate university physics students in traditional physics courses taking the same tests (20%).[4] A summer program at California State University San Marcos that also used the research-based *Physics by Inquiry* curriculum reported strong learning gains among in-service middle school and high school physics teachers, as measured by improvements in performance on physics concept tests. Delayed tests administered six to eight months after instruction found good to excellent retention of the learning gains. [5]

Students of teachers who participate in Arizona State University's "Modeling Instruction" in-service program have consistently shown much better performance on the "Force Concept Inventory" mechanics diagnostic test than students of teachers who had not been through that or any comparable program.[6] Other evidence shows that both pre-service and in-service teachers who participate in workshops using the Modeling method demonstrate greater gains on physics concept tests than do students enrolled in comparable courses that use only standard textbooks and instructional methods.[7]

1. This section draws on material from David E. Meltzer, "Research on the education of physics teachers," *in Physics Teacher Education: Research, Curriculum, and Practice*, edited by David E. Meltzer and Peter S. Shaffer (American Physical Society, College Park, MD, 2011), pp. 3-14.
2. TIMSS (Trends in International Mathematics and Science Study) is an international study of students' mathematics and science achievement.
3. TIMSS International Study Center, *TIMSS Physics Achievement Comparison Study* (TIMSS International Study Center, Chestnut Hill, MA, 2000). Available at: http://modeling.asu.edu/Evaluations/TIMSS_NSFphysicsStudy99.pdf.
4. Lillian C. McDermott, Paula R. L. Heron, Peter S. Shaffer, and MacKenzie R. Stetzer, "Improving the preparation of K-12 teachers through physics education research," *American Journal of Physics* **74**, 763-767 (2006).
5. Graham E. Oberem and Paul G. Jasien, "Measuring the effectiveness of an inquiry-oriented summer physics course for in-service teachers," *Journal of Physics Teacher Education Online* **2**(2), 17-23 (2004).
6. An early report is in David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher* **30**, 141-158 (1992), and a follow-up report is in Malcolm Wells, David Hestenes, and Gregg Swackhamer, "A modeling method for high school physics instruction," *American Journal of Physics* **63**, 606-619 (1995). The data are reviewed within a larger perspective by Richard R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *American Journal of Physics* **66**, 64-74 (1998). More recent data are discussed in an evaluation report prepared for NSF, available at: http://modeling.asu.edu/R&E/ModelingWorkshopFindings.pdf.
7. Meltzer, "Research on the education of physics teachers," Section IVC.ii.

The Rutgers University program for pre-service physics teacher education is based on a sequence of courses on physics-specific pedagogy, founded on physics education research. Evaluations of program participants show that their knowledge of both physics concepts and science processes (such as experiment design) improve dramatically over the course of the program, with final scores showing high proficiency. These objective measures were consistent with evaluations by the students' mentor teachers and science supervisors.[8]

Extensive studies of students who participate in the University of Colorado's "Learning Assistant" pre-service program have documented dramatic learning gains not only in introductory-level physics courses but in advanced-level courses as well.[9] Follow-up observations and interviews with former participants in the program indicate that teaching practices of first-year secondary science teachers who had been in the program are more closely aligned with national science teaching standards than practices of comparable first-year teachers who had not been part of the program.[10]

An in-service program at the University of Colorado engages physics and physical-science teachers in curriculum planning, and in research on their own classroom teaching practices. Together they review and reflect on their work from the standpoint of findings in the science education literature. A variety of written and video data indicate clear progress by the participating teachers toward teaching practices and ideas that are consistent with recommendations in the science education literature.[11]

8. Eugenia Etkina, "Pedagogical content knowledge and preparation of high school physics teachers," *Physical Review Special Topics - Physics Education Research* **6**, 020110-1–26 (2010).
9. S. J. Pollock, "A longitudinal study of the impact of curriculum on conceptual understanding in E&M," in *2007 Physics Education Research Conference [Greensboro, North Carolina, 1-2 August 2007]*, edited by Leon Hsu, Charles Henderson, and Laura McCullough, AIP Conference Proceedings **951** (AIP, Melville, NY, 2007), pp. 172-175; Valerie Otero, Steven Pollock, and Noah Finkelstein, "A physics department's role in preparing physics teachers: The Colorado learning assistant model," *American Journal of Physics* **78**, 1218-1224 (2010).
10. Kara E. Gray, David C. Webb, and Valerie K. Otero, "Are Learning Assistants better K-12 science teachers?" in *2010 Physics Education Research Conference [Portland, OR, 21-22 July 2010]*, edited by Chandralekha Singh, Mel Sabella, and Sanjay Rebello, AIP Conference Proceedings **1289** (AIP, Melville, NY, 2010), pp. 157-160; Kara E. Gray, David C. Webb, and Valerie K. Otero, "Effects of the Learning Assistant experience on in-service teachers' practices," in *2011 Physics Education Research Conference [Omaha, Nebraska, USA, 3-4 August 2011]*, edited by N. Sanjay Rebello, Paula V. Engelhardt, and Chandralekha Singh, AIP Conference Proceedings **1413** (AIP, Melville, NY, 2012), pp. 199-102.
11. Mike Ross, Ben Van Dusen, Samson Sherman, and Valerie Otero, "Teacher-driven professional development and the pursuit of a sophisticated understanding of inquiry," in *2011 Physics Education Research Conference [Omaha, Nebraska, USA, 3-4 August 2011]*, edited by N. Sanjay Rebello, Paula V. Engelhardt, and Chandralekha Singh, AIP Conference Proceedings **1413** (AIP, Melville, NY, 2012), pp. 327-330.

The Constructing Physics Understanding (CPU) project at San Diego State University included summer and academic-year workshops targeted at in-service high school teachers. These workshops included inquiry-based investigative activities developed through physics education research. High school students taught by workshop participants recorded higher scores on physics concept exams than students taught the same concepts by a very comparable group of teachers who had not taken the CPU workshops. The highest scores were recorded by students of teachers who had previous CPU experience and who had helped lead the workshops.[12]

An Israeli program utilized methods closely analogous to those employed by U.S. researchers. This program guided in-service physics teachers to develop, and use in their classrooms, curricular materials and instructional methods based on physics education research. These teachers' students performed better on tests of electromagnetism concepts than did students at the same schools who used standard instructional materials not based on education research results.[13]

The PTRA (Physics Teaching Resource Agent) program, sponsored by the American Association of Physics Teachers and funded by the National Science Foundation, has provided research-based workshops and curricular materials for in-service physics and physical science teachers since the 1980s.[14] Although peer-reviewed studies of the effectiveness of these workshops have yet to be published, preliminary research data suggest that students of long-term workshop participants make gains in physics content knowledge that are significantly larger than those made by students of non-participants.[15]

The programs described above are all specifically targeted

12. Douglas Huffman, Fred Goldberg, and Michael Michlin, "Using computers to create constructivist learning environments: Impact on pedagogy and achievement," *Journal of Computers in Mathematics and Science Teaching* **22**, 151-168 (2003); Douglas Huffman, "Reforming pedagogy: Inservice teacher education and instructional reform," *Journal of Science Teacher Education* **17**, 121-136 (2006).
13. Bat-Sheva Eylon and Esther Bagno, "Research-design model for professional development of teachers: Designing lessons with physics education research," *Physical Review Special Topics - Physics Education Research* **2**, 020106-1–14 (2006).
14. Larry Badar and Jim Nelson, "Physics Teaching Resource Agent program," *The Physics Teacher* **39**, 236-241 (2001); Teresa Burns, "Maximizing the workshop experience: An example from the PTRA Rural Initiatives Program," *The Physics Teacher* **41**, 500-501 (2003).
15. Karen Jo Adams Matsler, *Assessing the Impact of Sustained, Comprehensive Professional Development on Rural Teachers as Implemented by a National Science Teacher Training Program*, Ed.D. dissertation (unpublished), Argosy University, Sarasota, Florida, 2004. Also see the 2010 NSF Final Report for the AAPT/PTRA Rural Project, prepared by K. J. Matsler, available at: http://www.aapt.org/Programs/projects/PTRA/upload/2010-NSF-Final-Report.pdf.

"...physics teacher education programs *can* be effective if they are thoroughly grounded in physics education research and sharply focused on developing expertise with physics-specific pedagogy."

at high school physics and physical-science teachers. However, outcomes reported in studies of similar programs that focus on preparation of elementary-and middle-school physical-science teachers are consistent with the results discussed here. These studies offer further support for the promise of the research-based instructional methods recommended in this Report for education of future physics teachers.[16]

16. For example, Fred Goldberg, Valerie Otero, and Stephen Robinson, "Design principles for effective physics instruction: A case from physics and everyday thinking," *American Journal of Physics* **78**, 1265-1277 (2010).

Summary

The research investigations summarized here are relatively small in scale. However, their number, diversity, and consistency of outcome provide substantial evidence for the effectiveness of the physics teacher education methods recommended in this Report. They are also consistent with the long-standing practices and research findings of physics teacher education programs in many other countries that have demonstrated student learning outcomes superior to those observed in the United States.[17] The literature on physics teacher education both in the U.S. and around the world indicates clearly that physics teacher education programs *can* be effective if they are thoroughly grounded in physics education research and sharply focused on developing expertise with physics-specific pedagogy.

17. See Chapter 1 of this Report as well as Meltzer, "Research on the education of physics teachers."

Appendix A: Physics Department Survey Documentation

Introduction to Appendix A

Appendix A contains documents relevant to the T-TEP nationwide survey of physics departments, with follow-up phone interviews. T-TEP contracted with the American Institute of Physics Statistical Research Center (SRC) to conduct a survey of physics departments about their teacher education efforts. Appendix A.1 contains the full SRC report, including a detailed breakdown and discussion of the survey results. The complete survey instrument is shown in Appendix A.2. As a follow-up to the survey, departments with undergraduate physics teacher education programs that produced two or more graduates per year were probed in more detail with a phone interview. The telephone interview protocol developed and used by T-TEP is shown in Appendix A.3. Further details regarding the survey and phone interviews can also be found in Chapter 2: Data Sources and Methodology.

Appendix A.1: AIP Statistical Research Center Report

2009 Survey of Physics Department Chairs: Programs Preparing Students to Become High School Physics Teachers

Patrick Mulvey, Roman Czujko, and Starr Nicholson
AIP Statistical Research Center
October 2009

Introduction

APS, AIP, and AAPT convened a joint task force on physics teacher education. Among the goals of the task force are to examine the extent to which physics departments are involved in improving and promoting the education of future physics teachers, to identify physics departments that have efforts designed to prepare students for high school teaching, and to identify the features of physics education programs that are successful.

The task force understood that there were a broad variety of different programs designed to improve physics teacher education, including undergraduate programs, master's degree programs, pre-service programs, in-service efforts, concentrations, and specialized courses. In addition, these different efforts have different features and strengths.

The task force contracted with the Statistical Research Center (SRC) of the American Institute of Physics to conduct a survey of physics departments about their teacher education efforts. The task force decided that the survey should focus primarily on undergraduate programs in physics departments intended to prepare undergraduate physics majors for high school physics teaching. This survey was part of a much larger effort that included site visits and phone interviews with representatives of selected programs.

How the Survey Was Conducted

SRC staff members collaborated with the data collection subcommittee to develop a comparatively short questionnaire (about 20 questions). The questionnaire was designed to identify physics departments with undergraduate physics teacher education programs, to develop data on the number of graduates coming out of those programs and the number of faculty involved in the programs, and to identify the extent to which these programs included features of specific interest such as having a master teacher, and having a formal relationship with the education department on campus.

The survey was conducted exclusively on-line. A copy of the questionnaire instrument is provided in Appendix A.2. Chairs of the 754 departments that awarded a bachelor's degree in physics in 2009 were contacted by e-mail and invited to participate in the study. After the initial e-mail, department chairs who did not respond to the survey were contacted up to four more times during June and July of 2009. We received responses from 578 departments for a final response rate of 77%.

In addition to the survey, 26 responding departments with undergraduate physics teacher education programs were followed up with a phone interview. These interviews, conducted by the task force, were used to clarify departmental responses to the survey and to explore more deeply the circumstances at these departments. Six site visits were also conducted. In some instances the information obtained during a phone interview or site visit differed from what was provided on the survey. In 16 cases the survey response data on the number of graduates from their undergraduate physics teacher preparation program during the last two years was different from what was obtained in an interview or site visit. In these cases the interview or site visit data was used to replace the survey response data. In all but two of these cases, the number of graduates was decreased by 1 or 2 individuals.

Table 1. Undergraduate education programs in physics departments.

	N	Percent
Have an education program	206	36
With graduates	117	20
No graduates	51	9
New program	20	4
Missing degree data	18	3
No education program	372	64
Total responding departments	578	

Terminology

Have an education program: provides a concentration, track, or specialization, specifically designed to prepare students to become high school teachers.

With graduates: At least one bachelor's from teacher education program awarded during the last 2 years (classes of 2008 & 2009).

Of the 372 departments that did not have a an undergraduate education program:	
192	Have no physics teacher preparation efforts at the department or institution level.
125	Have physics teacher preparation efforts at the institution level only.
26	Have no undergraduate specialization, but do have courses or other specifically designed teacher preparation efforts at the department level.
21	Departments provided no information except that they don't have a departmental level teacher preparation program or courses.
8	Departments offer a master's degree in physics education.

Table 2. Undergraduate education program by highest physics degree offered.

	PhD-granting departments		Bachelor's and Master's granting Departments[1]	
Have an education program	N	%	N	%
With graduates	19	13	98	23
No graduates	8	6	43	10
New program	8	6	12	3
Missing degree data	8	6	10	3
No education program	99	70	273	63
Total	142		436	

No graduates: No bachelor's awarded from education program during the last 2 years.

New program: Education program is less than 2 years old and, thus, has no graduates.

No education program: No undergraduate concentration, track or specialization specifically designed to prepare students to become high school teachers.

Findings

Of the responding physics departments, 117 reported that they had a teacher education program and that they awarded at least one bachelor's degree from that program over the last two academic years. Ninety-eight of these programs were at departments that awarded either a bachelor's or master's as their highest physics degree. The other 19 programs resided in physics PhD-granting departments.

Combined, these departments awarded more than 200 physics bachelor's each year from their education programs. About 150 of these were awarded by bachelor's and master's-granting physics departments and another 50 per year graduated from physics PhD-granting departments.

FIfty-one physics departments indicated that they had a teacher education program that had, for various reasons, no graduates over the last two years. Another 20 physics departments indicated that they had begun a new program less than 2 academic years earlier and so they had not yet had an opportunity to graduate any teachers.

Virtually every department (over 94%) with an education program whether with graduates over the last two years, with no graduates, or new provided the name of an individual who could be contacted for more information about the teacher education program. The ability to identify a

1. Data for the 51 responding departments that offer a master's as their highest physics degree have been combined with the bachelor's-granting departments due to their similarities and the small number of master's programs.

Table 3. Selected characteristics of teacher education programs in physics departments			
	Program with graduates %	Program no graduates %	New program %
Recognition and rewards	29	6	25
Cooperates with Dept. of Education	92	86	85
Number of depts.	117	51	20

Table 4. Size of undergraduate program.				
Highest physics degree offered by department	Physics bachelor's from education program (2-year total) Average	All physics bachelor's[2] (2-year total) Average	 Typical Range[3]	Responding departments N
Bachelor's & Master's Depts.				
Educ program w/ grads	3	11	6 to16	98
Educ program no grads		8	4 to12	43
New Program		11	*	12
No program		9	4 to12	273
PhD-granting Depts.				
Educ program w/ grads	5	40	14 to 54	19
Educ program no grads		31	*	8
New Program		24	*	8
No program		28	12 to 38	99

* too few responding departments to provide reliable and accurate percentiles.

contact for additional information was viewed as one indicator that this might be an active program rather than one that exists on paper only.

Few departments reported that that there was recognition, support, or tangible rewards for the faculty members involved in their physics teacher education program. Departments that recognized and rewarded faculty involvement were more likely to have graduates from their program than those that did not.

Of physics departments that have programs designed to prepare undergraduate majors for careers in high school teaching, the vast majority (about 90%) indicated that they had either a formal or informal relationship with the education department on their campuses.

In fact, about 80% of the chairs who reported a connection with the education department were able to identify an individual in the education department who could provide additional information.

The survey included a question intended to determine whether departments had a Master Teacher engaged in their efforts to prepare high school physics teachers. The concept of a Master Teacher is new to many departments. Even though we described the characteristics and responsibilities of such an individual, the interpretation of what constituted a Master Teacher varied greatly. As a result, we determined that the data were neither accurate nor reliable.

SRC staff members used the number of physics bachelor's awarded over a two-year period as one indicator of the

2. Source for all physics bachelors: AIP annual *Survey of Enrollments and Degrees* in physics and astronomy.

3. Typical Range refers to the middle 50%, that is, the range from the 25th percentile to the 75th percentile.

Table 5. Physics faculty.		
Highest physics degree offered by department	Total physics faculty[4]	
	Average	Typical Range[5]
Bachelor's & Master's Depts.		
Educ program w/ grads	9	5 to12
Educ program no grads	7	3 to 8
New Program	8	*
No program	7	3 to 8
PhD-granting Depts.		
Educ program w/ grads	36	18 to 50
Educ program no grads	*	*
New Program	*	*
No program	30	18 to 36

* too few responding departments to provide reliable and accurate percentiles.

Table 6. Size of university.			
Highest physics degree offered by department	Total bachelor's degrees[6]		Number of universities
	Average	Typical Range	
Bachelor's & Master's Depts.			
Educ program w/ grads	1,434	704 to 1,988	97
Educ program no grads	793	328 to 1,039	42
New Program	1,290	*	12
No program	878	361 to 1,045	266
PhD-granting Depts.			
Educ program w/ grads	3,532	2,008 to 5,230	19
Educ program no grads	*	*	8
New Program	*	*	8
No program	2,973	1,465 to 3,870	96

* too few responding departments to provide reliable and accurate percentiles.

size of the department. These data are collected annually by the SRC.

Bachelor's and master's-granting physics departments that recently awarded physics education bachelor's tend to be larger than either those physics departments with no programs or those with programs that had no recent graduates. PhD-granting physics departments that recently awarded bachelor's from their physics education program tend to be larger than PhD-granting departments with no programs.

Within bachelor's and master's-granting physics departments, the number of degrees from the education program comprises a much larger proportion of all physics bachelor's awarded than is true of bachelor's awarded by PhD-granting physics departments.

4. Source of faculty data: AIP biennial survey of the Academic Workforce in Physics and Astronomy, 2007
5. Typical Range refers to the middle 50%, that is, the range from the 25th percentile to the 75th percentile.
6. Source of total bachelor's degrees: National Center for Education Statistics of the U.S. Department of Education.

Teacher education programs come in a broad variety of forms, and the terminology that individuals use to describe their programs is inconsistent. Thus, the number of bachelor's degrees awarded from the education programs as reported in this survey may be somewhat inflated. However, we are confident that the overall trends are correct.

The survey included a question intended to determine whether departments recruited students to participate in their physics teacher education program. Recruitment efforts varied greatly from department to department and the questionnaire did not provide guidance on how to categorize their efforts. As a result we do not have accurate and reliable data on recruitment.

SRC staff members used data collected by another SRC survey to describe the total number of faculty members in the physics department.

Physics departments that recently graduated bachelor's from their education programs tend to have somewhat more faculty members than physics departments with no programs. This is true of PhD-granting physics departments as well as departments that award a bachelor's or master's as their highest physics degree.

The survey included a question about the number of faculty members who were involved in efforts to prepare high school physics teachers. However, the questionnaire did not provide guidance about what constituted faculty involvement. Many chairs interpreted this question very differently than was intended. As a result we do not have accurate and reliable data on faculty involvement.

SRC staff members used data collected by the U.S. Department of Education to provide a picture of the size of the universities in terms of the total number of bachelor's awarded in academic year 2005-06 across all fields.

Physics departments that have teacher education programs with recent graduates tend to be in larger universities than physics departments with no programs. This trend is true of PhD-granting physics departments as well as departments that offer either a bachelor's or master's as their highest degree.

We had intended to incorporate data on the total number of education bachelor's awarded by each university as well as the total number of bachelor's in order to develop a scale reflecting the relative importance of the education major on campus. Unfortunately, education is a major that takes on very many different forms in different institutions. Despite our best efforts, we were unable to develop accurate and consistent data on bachelor's degrees awarded in education at each university in our respondent group.

Appendix A.2: Survey Instrument

PhysTEC Survey of Physics Department Chairs

1. Does your institution have a concentration, track, specialization or courses specifically designed to prepare students to become high school physics teachers? [Note: Such a program or courses might not be housed within the physics department]
   - ☐ No
   - ☐ Yes

2. Does the physics department have a concentration, track, specialization or courses specifically designed for preparing students to become high school physics teachers?
   - ☐ No
   - ☐ Yes

If "No, directed to question #3.
If "Yes," directed to question # 5.

3. Are any physics faculty members discussing the possibility of initiating a concentration, track, specialization or courses specifically designed for preparing students to become high school physics teachers?
   - ☐ No
   - ☐ Yes

If question #1 = "No," directed to question #19.

4. Who would be the appropriate person to contact to learn more about the institution-level program or courses designed to prepare students to become high school physics teachers?

Name:	
Phone:	
Email:	

Directed to question #19

Departments with an education program (question #2 = "Yes") continue with question #5.

5. You indicated your department has a concentration, track, specialization or courses specifically designed to prepare students to become high school physics teachers.

At what level are these efforts?
- ☐ Undergraduate student level
- ☐ Graduate student level
- ☐ Both the undergraduate and graduate student level

Departments with efforts at the undergraduate-level received question #6.

6. Which of the following best describes the physics department's undergraduate-level concentration, track, specialization or courses specifically designed to prepare students to become high school physics teachers?
   - ☐ A major or minor in physics that includes a track, concentration, or specialization designed for future high-school physics teachers.
   - ☐ Individual course(s) designed specifically for future high-school physics teachers, but which are not included in a separate bachelor's degree program for future teachers.
   - ☐ Other efforts specifically designed to prepare undergraduate students to become high school physics teachers.

7. Which of the following best describes the physics department's graduate-level concentration, track, specialization or courses specifically designed to prepare students to become high school physics teachers?
   - ☐ A master's degree in physics that includes a track, concentration, or specialization designed for future high-school physics teachers.
   - ☐ Individual course(s) designed specifically for future high-school physics teachers, but which are not included in a separate master's degree program for future teachers.
   - ☐ Other graduate-level specific high school physics teacher preparation efforts not covered above.

Departments with efforts at the bachelors-level received this instruction:

Please answer the following questions concerning your efforts at the undergraduate-level designed to prepare students to become high school physics teachers.

Departments with efforts only at the graduate-level received this instruction:

Please answer the following questions concerning your efforts at the graduate-level designed to prepare students to become high school physics teachers.

8. Who within the physics department could we contact for information about your efforts to prepare high school physics teachers?

   Name: ☐

   Phone: ☐

   Email: ☐

Only departments with degrees (including minors and concentrations) designed to prepare students to become high school physics teachers received questions #9, #10, and #11.

9. When did the physics department's track, concentration, or specialization intending to prepare future high school teachers start?

   Academic year: ☐

10. During the last 2 academic years (2007-08 and 2008-09) how many students completed your departments track, concentration, or specialization designed to prepare them for high school physics teaching?

    (Estimate if necessary) ☐

    Number of graduates: ☐

11. Do students need to formally apply to the physics department's high school physics teacher preparation concentration, track or specialization?
    - ☐ No
    - ☐ Yes

Departments offering only course work designed to prepare students to become high school physics teachers received questions #12 and #13.

12. When were the course(s) designed specifically for future high-school physics teachers first made available to students?

    Academic year: ☐

13. During the last 2 academic years (2007-08 and 2008-09) how many students enrolled in courses designed to prepare them for high school physics teaching?

    (Estimate if necessary) ☐

    Enrollment number: ☐

Departments offering either degrees or course work designed to prepare students to become high school physics teachers received the remainder of the questions.

14. Do you recruit students to participate in your concentration, track, specialization or course(s)?
    - ☐ No
    - ☐ Yes

    (14a) Please briefly describe your recruiting efforts:

    ☐

15. How many physics faculty members are involved with your efforts to prepare high school physics teachers?

    Number of faculty: ☐

16. Is a Master Teacher engaged in your efforts to prepare high school physics teachers? Definition: A Master Teacher is an experienced high school physics teacher who may recruit and mentor new teachers, teach methods courses, build relationships with schools, and contribute in other significant ways to teacher education programs.
    - ☐ No
    - ☐ Yes

    (16a) Please provide the name and contact information for this master teacher.

    Name: ☐
    Phone: ☐
    Email: ☐

17. Is there recognition, support, or tangible rewards for the faculty members involved in your efforts to prepare high school physics teachers (e.g. release time, admin, support, etc.)?
    - ☐ No
    - ☐ Yes

(17a) Please briefly describe the recognition or support given to the faculty involved:

18. Is there a cooperative relationship between your department's efforts to prepare high school physics teachers and the school of education?

- ☐ Yes, there is a formal relationship
- ☐ Yes, there is an informal relationship
- ☐ No
- ☐ I don't know

(18a) Who in the school of education would be the best person to contact if we wanted to learn more about this relationship?

Name:	
Phone:	
Email:	

19. This survey was completed by:

Name:	
Phone:	
Email:	

Appendix A.3: Interview Protocol

Date:
Interviewee:
Institution:

Hi, is this [name of interviewee]? I'm ___________; I'm a member of the national Task Force on Teacher Education in Physics established by the American Physical Society, AAPT and AIP. Your chair identified you as a person knowledgeable about the department's efforts to prepare high school physics teachers. I'd like to ask you a few questions about your program, which will take 20 minutes or less. We're collecting this information to better understand the state of physics teacher preparation across the country. We will only report information in aggregate, and will not publish information that can identify individual institutions. Does all this sound OK?

1. Your chair indicated ___ physics faculty members are involved in efforts to prepare high school physics teachers.

    a. Who are the lead faculty or staff involved, and what are their roles in teacher preparation?

    b. Is there a person involved in the program who has extensive high-school teaching experience?

2. Your chair reported that the physics department has a concentration, track, or specialization specifically designed for preparing students to become high school physics teachers, and these programs exist at **{the undergraduate level / the graduate level / both the undergraduate and graduate level}.**

    a. Could you briefly describe your programs?

    b. Your chair reported during the last 2 academic years, ___ students completed your department's track, concentration, or specialization designed to prepare them for high school physics teaching. Could you confirm this?

3. Your chair indicated **{there is / there is not}** recognition, support, or tangible rewards for the faculty members involved in your efforts to prepare high school physics teachers, for example release time or administrative support.

    a. Would you agree?

    b. Please describe the level of support for your programs within the physics department and at the university.

4. Do you have courses designed specifically for future physics or physical science teachers? If so, please describe each course and give typical enrollments.

5. Your chair indicated that your department **{does / does not}** recruit students into your program.

    a. Could you confirm this?

    b. *(If there is recruiting)* What are methods of recruiting have you found to be effective?

6. Do students in your program receive advising or mentoring? If so, please describe.

7. Early teaching experiences provide students opportunities to experience teaching early in their careers, which can help them develop pedagogical skills and decide if they really want to pursue teaching.

    a. Do you provide early teaching experiences for students? If so, please describe.

    b. Who supervises student teachers and makes field placements?

8. Do you keep track of program graduates, or continue to provide support after they graduate? If so, please describe.

9. Your chair indicated **{there is /there is not }** a cooperative relationship between your departments efforts to prepare high school physics teachers and the school of education

    a. Could you confirm this?

    b. Please describe the relationship with the school of education.

10. What barriers to you see to further development and improvement of your program?

11. Can we call you back for a follow-up discussion?

Appendix B: Site Visit Documentation

Introduction to Appendix B

This appendix contains documents T-TEP used to identify and conduct site visits to outstanding physics teacher education programs. Appendix B.1 contains the letter sent to all physics departments and the letter sent to schools of education soliciting nominations for site visits. Once institutions were selected for site visits (through a procedure described in the Methodology chapter), a site visit team was assembled, typically including one T-TEP member from an academic institution, one professional society liaison, and one volunteer from outside T-TEP. The names of site visit volunteers are listed in Appendix B.2. Prior to the site visit, each institution was sent a package including a letter to the site visit host (Appendix B.3), a memorandum of understanding (Appendix B.4), and a questionnaire (Appendix B.5). Responses to the questionnaire provided detailed program information that informed the site visit team and supplemented information gathered during the actual visit.

Appendix B.1: Letters Soliciting Nominations

Dear [physics chair's name],

I am writing to you today to ask if your department runs a significant program in high school teacher education. As a member of a national task force on teacher education in physics, we intend to conduct site visits to exemplary programs to document and disseminate ideas from such programs.

The American Physical Society, the American Association of Physics Teachers, and the American Institute of Physics have been working together throughout this decade to address the dramatic shortage of highly qualified teachers of high school physics. These Societies have worked to encourage physics departments to engage with their respective schools of education in addressing this issue. As a part of this endeavor, they recently formed a national task force to help identify and document innovative and effective programs that have resulted in educating many more highly qualified teachers of physics.

This task force is now working to identify programs of significant merit for further study. Our aim is to conduct site visits to some of the most noteworthy and productive programs and to broadly disseminate the results of their efforts throughout the physics and teacher education communities.

Today, we come to you to inquire if you feel the program at your university is one that we should visit and document. We are not describing a set of criteria or particular measures of success, as we feel there are a number of interesting programs of many different stripes that might be of interest to the community. If you feel that your program (or another that you are aware of) would be worth such study, we invite you to reply with the following information:

- Name and contact information of a person with whom we can speak concerning the program
- A brief (no more than one page) description of the program and the reasons why you think it would be of interest to the community
- The number of teachers of high school (9-12) physics educated by the program in the past five years
- Any supplementary materials that will help describe the program. This can include a website URL, recruiting materials, course descriptions, or other materials. We can only accept electronic materials (no hard copies).

We would like this information returned by 1 July 2008. Please send the information to Ted Hodapp, Director of Education at the American Physical Society: (hodapp@aps.org). If you have any suggestions, questions, or other comments, please feel free to contact Ted, or the chair of the site selection subcommittee, Valerie Otero, University of Colorado at Boulder (valerie.otero@colorado.edu).

Thank you for your help in this matter.

For the task force,

Ted Hodapp
Director of Education and Diversity
American Physical Society

Task Force members include:

Eugenia Etkina (Rutgers University)
David Haase (North Carolina State University)
Jack Hehn (American Institute of Physics)
Warren Hein (American Association of Physics Teachers)
Ted Hodapp (American Physical Society)
Charles Holbrow (American Association of Physics Teachers)
Drew Isola (Michigan Public Schools)
Eugene Levy (Rice University)
George Pinky Nelson (Western Washington University)
Valerie Otero (University of Colorado)
Monica Plisch (American Physical Society)
Mary Ann Rankin (University of Texas at Austin)
Jim Stith (American Institute of Physics)
Stamatis Vokos, chair, (Seattle Pacific University)

Appendix B.2: Letter to Site Visit Host

Dear (Program Chair/Coordinator/Faculty Member):

The purpose of the site visits of the Physics Teacher Task Force is to investigate successful programs that prepare qualified teachers of physics. We are gathering data to produce a report for national circulation about excellent programs in physics teacher education. The task force is a joint effort of American Physical Society, American Association of Physics Teachers, and American Institute of Physics. The site visits are supported with funding from the Physics Teacher Education Coalition. **The focus of the task force is on <u>teachers qualified to teach physics</u>. The task force will undertake three main lines of inquiry:**

1. *Increasing the number of qualified teachers* Are there generalizable, yet flexible, strategies that institutions (and in particular, physics departments and schools or colleges of education) can employ?

2. *Identifying best practices* Are there effective (a) strategies in recruitment, (b) models of professional preparation, and (c) higher education systems of support during the first three years of teaching?

3. *Research, Policy, Funding Implications* Are there characteristics of physics departments, special partnerships, and types of institutional support and extramural funding that foster effective programs? Are there important new research agenda in teacher professional education and development in physics, which can be identified and promoted? What new measures of discipline-based teaching effectiveness need to be developed? What new funding avenues and policy changes need to be in place to support these cutting-edge research and development efforts?

The visit is not intended to evaluate directly the strengths and weaknesses of your physics teacher preparation program. The eventual goal is to be able to characterize those elements that are important (or in some cases crucial) for planning, developing, implementing, and sustaining successful programs that prepare qualified teachers of physics.

The attached memorandum of understanding explicitly states the terms under which the site visit will be conducted. Please sign it, return it to me, and keep a copy for your files. Also attached are several questions whose answers should be provided to the Physics Teacher Task Force before the site visit. The site visit team will consist of approximately three physics educators including one of the members of the task force.

The task force appreciates you agreeing to participate in the site visit program. Your contribution will help other physics teacher preparation programs design constructive responses to the growing need for qualified physics teachers.

Sincerely,
Stamatis Vokos
Chair, Physics Teacher Task Force

Appendix B.3: Memorandum of Understanding

Agreement by and between THE NATIONAL PHYSICS TEACHER TASK FORCE, and **XXX** (hereinafter "Local Site").

It is agreed:

- The Local Site will cover all local transportation during the visit for the three-member site visit team.
- The Local Site will make appropriate hotel reservations for the site visit team.
- The National Physics Teacher Task Force will cover all travel, hotel and meal expenses for the site visit team (including transportation from the airport to the hotel).
- The Local Site will provide the site visit team with written responses to a set of questions about their program at least two weeks prior to the site visit.
- In consultation with the site visit team leader, the Local Site contact will set up a schedule of appointments with small groups of faculty (both in the Physics Department and the School of Education and outside the program as appropriate), students (including the graduates), support staff, and administrators.
- After the site visit, the site visit team will provide the Local Site contact with a written report of the team's findings within one month of the site visit. The report is written for the physics program. The Local Site contact may share the report with the institution's administration at their discretion. The task force will seek permission of the Local Site before using any of the data in the report in a way that links the data directly to the Local Site. The National Physics Teacher Task Force may ask for additional data and comments as it prepares a case studies document.

______________________________ Date: ______________________

Stamatis Vokos, Chair
National Physics Teacher Task Force

______________________________ Date: ______________________

Local Site contact

Appendix B.4: Site Visit Questionnaire

The site visit will be much more productive both for the Task Force and for the host Physics Teacher Preparation Program if the site visit team members have some information about the host Physics Teacher Preparation Program in advance of the actual visit. The Physics Teacher Preparation Program Questionnaire provides insights on many aspects of the information we would like to receive. Please provide the following information two weeks prior to the scheduled site visit.

1. Personnel
    A. Physics and Education Faculty by rank (if your institution has rank) who are engaged in physics teacher education and give years in service for teacher preparation.
    B. Describe briefly the affiliations of the faculty and staff who participate in the program, their education, teaching experiences and research interests.
    C. Describe activities that the education and physics faculty and staff engage in together.
    D. Do any of the faculty conduct research on teacher preparation or teacher professional development? If so, describe briefly.
2. Students
    A. The number of teachers that your organization certifies in each year broken down by elementary and secondary for each of the past 6 years.
    B. The number of those who received science teaching certification degree with the special information about those who are prepared to teach physics (list majors and minors) for each of the past 6 years. Explain why you think that these individuals are prepared to teach physics.
    C. If the physics major is not required for certification, list the required physics courses for prospective teachers of physics.
    D. If possible, roughly what fraction of your graduates actually goes into K-12 teaching? Roughly, how many remain after 3 years? 5 years? Alert us to any historical trends in that data. Provide names and contact information of 5-10 recent alumni and information about their employment.
    E. What are the days/times when classes specifically offered for physics teacher candidates are offered?
    F. What are the days/times when teacher candidates could be observed in a teaching activity?
    G. What scholarships or financial assistance are available to physics teacher candidates?
3. Program
    A. Provide a brief narrative about your program of preparation of physics teachers. Outline the critical elements of the underlying philosophy of the program particularly focusing on what you consider to be the most important components and novel features that you believe are particularly successful.
    B. What changes have you implemented that helped increase the number of students in the program.
    C. How do you recruit students for the program?
    D. How do you mentor/advise students while in the program?
    E. How do you stay in touch with the students after they leave the program?
    F. Is your program nationally accredited or pursuing national accreditation?
    G. List of courses in which physics teacher candidates learn teaching skills in physics. Provide syllabi.
    H. The typical enrollments in each of the courses listed in H above.
    I. Provide a brief description of early teaching experiences of prospective high school teachers of physics: when they occur, the length, the choice of sites, the activities that candidates partake, and the assessment of these activities.
    J. Describe research experiences (including when they occur) that physics/physical science candidates have or any other experiences where they learn about scientific inquiry firsthand.
4. If you have other general information about your physics/physical science teacher preparation program including recruiting brochures, course catalog information, college and physics program (if there is one), mission statements, course or faculty evaluation forms, and so on, we would appreciate receiving copies of that information.

Appendix B.5: Site Visit Volunteers

Eric Brewe	Assistant Professor of Science Education Florida International University
Charles Coble	Co-Director, Science and Mathematics Teacher Imperative (SMTI) Association of Public and Land-grant Universities
Larry Coleman	Professor of Physics, Emeritus University of California, Davis
Nicole Gillespie	Director for Teaching Fellowships Knowles Science Teaching Foundation
Paula Heron	Professor of Physics University of Washington
George (Pinky) Nelson	Former Director, Science, Mathematics, and Technology Education Program Professor Emeritus of Physics and Astronomy Western Washington University
Mel Sabella	Associate Professor of Physics Chicago State University
Rachel Scherr	Senior Research Scientist Department of Physics Seattle Pacific University
Peter Shaffer	Professor of Physics University of Washington

Appendix C: Site Visit Report Summaries

Introduction to Appendix C

This Appendix contains summary reports on physics teacher education programs that T-TEP members visited. These reports are intended to illustrate some of the best U.S. programs identified by T-TEP, determined both by the number of graduates per year and the quality of the program. This Appendix is not intended to be an exhaustive list of the best programs, and there are almost certainly programs that T-TEP did not visit that could have been featured here. The procedure by which programs were selected for on-site visits is described in the Methodology chapter. Each summary begins with a brief overview of the institution and the physics department, and then lists the key program personnel and describes their primary responsibilities. The main features of each program are discussed and particularly notable or unusual aspects are highlighted. In addition, a brief historical review of each program is provided to offer insight into how site leaders addressed challenges and overcame obstacles in building successful programs.

Appendix C.1: Arizona State University (Tempe, AZ)

Through its Modeling Instruction Program, Arizona State University built a national in-service teacher training effort and developed a large, enthusiastic, and self-sustaining community.

Notable Features

- instructional method and curricular materials developed and tested over two decades
- courses and workshops led primarily by experienced master teachers
- sequence of courses focused on the teaching and learning of physics

Overview

Arizona State University (ASU) is a very large state university in the Phoenix metropolitan area with a large and highly ranked research-oriented physics department. The department awards about 20 B.S. and 12 Ph.D. degrees per year. Almost all physics teacher education at ASU takes place in the Master of Natural Science (MNS) degree program, designed for and dedicated to the professional development of in-service physics and physical science teachers. The MNS program is founded on the Modeling Instruction[1] method developed at ASU in the early 1990s. The program incorporates "Modeling Workshops" taught by experienced K-12 teachers as well as additional professional development courses taught by physics faculty. Although all courses in the program can be used to satisfy degree requirements, many of those who enroll are not actually in the degree program and take just one or two courses for the purposes of professional development.

Although endorsed and supported by the physics department, ASU's in-service program has for 20 years operated primarily through summer courses and workshops aided by federal and state grant support. More than 600 physics teachers, drawn from all over the country, have participated in the Modeling Workshops at ASU since their inception in the 1990s. The average annual participation is on the order of 100 teachers; about half are new to the program and half are returning teachers. About 6 MNS degrees are awarded each year. The leaders of the program estimate that about two-thirds of the nearly 200 physics teachers in the Phoenix metropolitan area have participated in at least one workshop, as have about half of all physics teachers in Arizona. Thousands more teachers have participated in workshops around the country led by former program participants. Apart from this in-service program, ASU has a variety of routes toward certification of pre-service physics teachers that, collectively, have a relatively small annual production (average total of less than 1 per year).

Leadership, Collaboration, and Administrative Support

The MNS Degree Program was founded by emeritus physics professor David Hestenes, who still plays a major role in strategic planning and overall guidance. Physics faculty member Robert Culbertson currently oversees the program, and Jane Jackson provides day-to-day leadership. A significant part of the program's resilience is due to its leaders' abilities to raise grant funding as well as its built-in source of income through summer workshops – factors especially important to the university administration, which is focused on the bottom line. This makes it possible for both the physics department and the university administration to continue to provide an institutional home for the program, along with some degree of logistical, administrative, and financial support. Jackson is continuously involved in promoting the program, building the national network of "Modelers" (teacher supporters of the Modeling program), and working to raise grant funds to keep the program functioning.

Program Description

ASU's Modeling Instruction program focuses on training existing science teachers. It was founded in the early 1990s by ASU physics professor David Hestenes, based in part on work done with his graduate student and veteran high-school teacher Malcolm Wells. Modeling Instruction integrates insights from physics education research with the classroom experience of expert teachers. Teachers engage students in developing mathematical models of physical behavior, and then evaluating and applying these models in concrete situations.

In 2002, the university instituted a "Master in Natural Science" (MNS) degree, which provided additional structure and status for the Modeling Instruction Program at ASU. The MNS program consists of a series of courses on physics and physics pedagogical content knowledge also known as Modeling Workshops. The courses can lead to the MNS degree or to acquisition of "highly qualified" status as defined by the Arizona Department of Education. The workshops and courses are designed specifically for in-service teachers, many of whom are crossover (i.e., out-of-subject-area) teachers. Participants may take just one or two of the courses offered during a single summer, or an extended series of courses over several summers that may lead to the MNS degree. There are also four follow-up workshops scheduled on Saturdays throughout the school year to pro-

1. See http://modelinginstruction.org/researchers/publications/what-is-modeling-instruction/.

vide support and encouragement to novice Modelers who are close enough to ASU to attend.

A number of distinctive features characterize the program:

- Many courses are led by highly experienced secondary-school teachers who speak the language and address the culture of the classroom.
- Workshops are scheduled during the summer to be accessible to in-service teachers.
- The program gives teachers the opportunity to earn graduate credit.

Many classes are highly interactive—teachers experience for themselves what they will be teaching by playing the role of students in a class led by master teachers. Participants work in groups, using laboratory equipment and computers to investigate a series of physical systems and develop and test mathematical, graphical, and descriptive "models" to characterize the nature and behavior of these systems.

The programs are affordable for local teachers. For Arizona teachers, the program has been able to obtain state grant funds nearly every year to cover much of the cost. The loss of NSF funding support has made the workshops significantly more expensive for out-of-state teachers.

The MNS program is a highly coherent program deeply rooted in Modeling Instruction pedagogy and primarily geared for in-service science teachers with some physics background. Summer coursework is structured into three categories: (1) physics pedagogy, including mechanics and electricity & magnetism; (2) interdisciplinary science, including integrated mathematics and physics; and (3) contemporary physics, including structure of matter and physical science with math modeling. Most courses in categories 2 and 3 are offered on a rotating basis over several summers. While subject to faculty oversight, most courses in category 1 as well as some courses in category 2 are taught by teams of outstanding in-service physics teachers. (This is consistent with "peer coaching," as endorsed in the National Science Education Standards.) In addition, all those seeking an MNS degree are required to carry out small-scale research projects in their own classrooms. A total of 30 graduate credit hours are required for the MNS degree: 15 credit hours from physics pedagogy and interdisciplinary science courses, and a minimum of six credits in contemporary physics courses.

The Modeling Instruction Program and associated MNS Program have fostered an active teacher community. Many of the teachers T-TEP interviewed shared how useful it was to be able to stay connected with other Modelers by e-mail and the listserv during the school year to share ideas and ask for help. These teachers looked forward to seeing each other during summers when they would attend or help lead workshops and courses in the program.

Program Contact

Dr. Robert Culbertson
Department of Physics
Arizona State University
P.O. Box 871504
Tempe, AZ 85287-1504
Phone: (480) 965-0945
E-mail: robert.culbertson@asu.edu

Appendix C.2: University of Arkansas (Main Campus, Fayetteville, AR)

The arrival of an enthusiastic faculty champion to spearhead reforms in physics education led to dramatic increases in the numbers of physics majors and physics teachers.

Notable Features

- dramatic advances following arrival of program champion dedicated to physics education
- flexible program that incorporates multiple routes toward becoming a high-school physics teacher
- active collaboration between physics and education departments

Overview

The University of Arkansas at Fayetteville is the flagship institution of the state system; its physics department has a thriving undergraduate program and graduates approximately 20 majors per year. It has the only physics graduate program in the state, granting about 4 Ph.D.'s per year. Physics teacher preparation began after the department recruited a faculty member in 1994 who had a primary interest in physics education. This faculty member, Gay Stewart, led the department's successful efforts to obtain several grants to support physics teacher education, including grants from PhysTEC and the NSF Noyce Scholarship program, state and national Math Science Partnership (MSP) grants, and others. The overall outcome was an increase in the number of University of Arkansas graduates certified to teach physics from nearly zero to 5-7 per year.

Leadership, Collaboration, and Administrative Support

Stewart leads teacher education efforts in the physics department. Prior to kick-starting Arkansas' physics teacher preparation efforts, Stewart had led efforts to reform the undergraduate program, including revisions to the introductory physics courses, changes in advising procedures, and introduction of modified degree plans; these reforms led to a dramatic increase in the number and quality of physics majors. This set the stage for Stewart to begin recruiting these majors to become teachers. Stewart was joined by a second PER faculty member in 2001 who helped in all these efforts, and the numbers of majors and teachers increased further.

Stewart recruits students to become physics majors and physics teachers and remains in regular contact with them both during their program and after graduation. Her work in physics education is seen as a priority by the chair of the physics department, who indicated that he would hire another faculty member with a similar focus if Stewart were no longer in the department. The physics department is regarded as a model for other departments by the dean and other upper-level administrators for its excellent programs. Stewart receives strong support from university administrators, and the department allocates resources, including additional graduate TAs, to support course reforms. Two physics faculty members now collaborate with Stewart on physics education efforts.

Stewart is active within the physics education research (PER) community, and is familiar with PER-based instruments, pedagogies, and teaching practices. She has physics research experience, as well as experience directing large programs. As a physics faculty member, she has expertise to work with teacher candidates on their understanding of physics content and on issues about teaching physics content to students. She creates a nurturing yet rigorous environment for teacher candidates, and provides individual advising and customized degree tracks for students. Stewart has worked closely with the university's College of Education and Health Professions to make appropriate changes to the teacher education program in order to increase the number and quality of physics teachers; for example, decreasing the credit-hour requirement for admission made the program more accessible. Stewart also maintains close contact with local school district officials.

Program Description

Each prospective physics teacher at Arkansas works through a program that is customized to his or her needs and schedule. The variety of pathways (listed below) offer considerable flexibility, attracting students who might not otherwise pursue physics teaching. All pathways lead to certification in "7-12 earth and physical science," which requires 12 credit hours in physics, although UA graduates exceed this minimum requirement.

- The "traditional" physics teacher preparation program is a 5-year Master of Arts in Teaching (MAT) program, with 4 years needed to complete the Bachelor of Arts or Bachelor of Science in physics and the fifth year in education courses that lead to secondary certification in physical science/geosciences. During the final semester of the MAT program, students spend 4 days per week student teaching in grade 7-12 classrooms and one day per week in courses at the university. There is also an MAT program offered by a different campus in the state, which allows students to be teachers of record and be paid by the schools during the MAT year.
- The "nontraditional licensure" or alternative certification program allows students to begin teaching imme-

diately after their bachelor's degree while completing requirements for full certification. This has been an important option for students who cannot afford an extra year of study to complete the MAT program. When Noyce Scholarship funding became available (see below), fewer students chose this route.

The Master of Arts in Physics Teaching is a degree program for in-service teachers to add certification in physics. It emphasizes content and pedagogy needed for teaching physics. This program also prepares two-year college faculty.

No matter which pathway a student chooses, Gay Stewart provides intellectual leadership, consistent support, and professional nurturing throughout the program. Advising continues into the first few years of teaching. The director of the physics education program is in communication with the director of field placements, and makes an effort to place student teachers with excellent, experienced, reform-minded teachers who are often graduates of the program. The program director organizes professional development programs that provide induction support for new teachers, and encourages program graduates to participate.

The program includes one course specifically targeted toward the development of physics pedagogical content knowledge. This course incorporates an experiential learning program in which students work as Learning Assistants or peer instructors in an introductory physics course, with a guided-inquiry approach to instruction. The course may be taken for up to 9 credit hours, focusing on different topic areas. In addition, many students enroll in independent study courses with the program director, in which they become familiar with physics education research literature and physics-specific pedagogy. The program director also arranges for other teaching experiences for future teachers, including internships at local high schools with excellent physics teachers.

One key factor in Arkansas' success in recruiting, according to graduates interviewed by the Arkansas faculty, is the array of excellent, engaging introductory physics courses taught by physics faculty members who demonstrate a deep commitment to the quality of their teaching. Another key factor in recruiting teachers is that when students express interest in K-12 teaching, physics faculty explicitly discuss it as a valid career choice and provide excellent advising and support to physics majors who make this choice. The Learning Assistant program, for which students receive credit instead of pay, is an additional mechanism for recruiting students to teaching careers and augmenting the teacher certification program. In addition, a Noyce Scholarship program provides critical financial support for students to complete their education to become physics teachers, which often requires an extra year of coursework beyond the bachelor's degree.

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Appendix C.3: Brigham Young University (Provo, UT)

Brigham Young University produces more qualified physics teachers than any other university in the United States.[1]

Notable Features

- large-enrollment program with multiple entry points
- close mentoring and advising of teacher candidates by expert physical science teachers
- tenure-track faculty position dedicated to physics teacher education

Overview

The physics department at Brigham Young University (BYU) has planned and built a program for physics teacher education that is compatible with the unique mission of the university. This mission, which places great emphasis on teaching and education, arises from the University's affiliation with the Church of Jesus Christ of Latter-day Saints. The physics department graduates approximately 55 physics majors each year (among the top five of all departments in the country), and an average of 14 physics teachers per year (including majors in physics teaching and in teaching physical science), more than any other department in the United States. More than 95% of graduates who are certified get teaching jobs, and retention rates are very high. Several high schools near BYU have expanded their physics programs as a result of the increased supply of well-prepared physics teachers and greater student demand for physics.

The high priority of undergraduate education within the university seems to affect every aspect of this thriving program. Nearly all physics faculty invest substantial effort in their teaching, and unfavorable tenure decisions happen as frequently for problems with teaching as for problems with research. The Mormon religion strongly values education, and an emphasis on developing teaching skills from an early age motivates students to consider a career in teaching. Such an environment supports the legitimacy of the teacher education program within the physics department. The fact that BYU is largely supported by the Mormon Church provides a stable source of funding for programs and fosters cooperation between departments rather than competition.

1. According to data collected by T-TEP.

Leadership, Collaboration, and Administrative Support

In 2000, physics professor Robert Beck Clark was recruited from Texas A&M, where he had led a physics teacher education program. Clark envisioned and laid the groundwork for BYU's program as it stands today. In 2004, the School of Education transferred a faculty position to the physics department, following a precedent established in other disciplines for housing secondary teacher education faculty in respective disciplinary departments. Clark recruited high school teacher Duane Merrell to the tenure-track position for physical-science teacher education. Merrell's responsibilities are wholly concerned with teaching physical-science teacher education courses and mentoring student teachers. He enjoys strong support from the faculty, who often go to him for advice on teaching, and has been highly successful at bringing in grant funding.

The School of Education hires a master teacher on a two-year rotating basis as a Clinical Faculty Associate (CFA) to assist Merrell in recruiting students, teaching courses, and observing students in their practicum placements. CFA positions depend on strong ties with local school districts, which release master teachers for two years to work in university teacher preparation programs in exchange for new BYU graduates who are mentored by the master teacher. Overall, BYU provides extremely strong administrative support for teacher education, and the physics chair indicated he would restructure other programs before cutting teacher education.

Program Description

The physics teacher preparation program at Brigham Young University is a four-year undergraduate program in which students may receive a Bachelor's of Science degree in either physics teaching or in teaching physical science. The program includes:

- two physics-specific pedagogy courses (for physics credit) and two physical science methods courses; each methods course involves several hours of experience in K-12 schools;
- five secondary education courses from the school of education, which include topics such as multicultural education, educating students with disabilities, adolescent development, classroom management, and technology in the classroom;
- physics coursework: physics teaching majors take three fewer courses than a full physics major, and physical science teaching majors take the equivalent of a physics minor with additional coursework in chemistry and earth science;

- student teaching for a full semester, instead of the research project required for full physics majors. Student teacher placements and supervision are the responsibility of the physics department, as is the supervision of pre-service teachers who are doing internships (with a temporary license) in K-12 schools.

While there is a recommended order in which to take courses, there is a large amount of flexibility in the program to accommodate students who make the decision to join the program at various times during their undergraduate career. Merrell, the director of the program, has enough power within the institution to tailor requirements to meet the needs of the students. This flexibility appeared to be an important aspect of recruiting students to the program.

Merrell has a close advising relationship with all students, and provides intellectual leadership, consistent support, and professional nurturing throughout the program and after graduation. Merrell teaches all the physics pedagogy classes, and he or the CFA visit each student teacher at least once a week. He frequently visits first- and second-year teachers as well. One student referred to Merrell as his "right-hand man," expressing the sentiment that he is a great resource.

Future teachers are placed in carefully selected classrooms for early teaching experiences and student teaching. The philosophy at BYU is that these placements must be with excellent, experienced, reform-minded teachers, many of whom are graduates of the program. This is facilitated by strong communication between Merrell and the director of field placements, and an advisory board of cooperating teachers. Student teachers are often placed in two-person teams that require fewer mentor teachers and foster more dialogue than individual student-teacher placements.

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Appendix C.4: Buffalo State College (Buffalo, NY)

Buffalo State College has educated a large number of in-service teachers of physics through its Master's program and related professional development activities.

Notable Features

- Master's degree program that produces a significant number of graduates
- a group of faculty dedicated to physics teacher education
- physics education research results infused into the curriculum

Overview

Buffalo State College (BSC), also known as SUNY College at Buffalo, is a regional institution with a significant focus on teacher education. It is a former normal school and graduates nearly 500 students each year with education degrees. The physics department has a half-dozen faculty with additional staff support, and graduates about 3 physics majors per year (about half are physics education majors). BSC's close proximity to SUNY Buffalo, a large research-intensive university with a physics Ph.D. program and a large engineering school, allows BSC physics students to increase their options in undergraduate research. In contrast with the small number of undergraduate physics education majors, BSC typically graduates four or five Master's students in physics education each year. The Master's program is designed for teachers already certified in secondary science or math seeking to add an endorsement in physics and/or to deepen their knowledge of physics and physics teaching methods.

Leadership, Collaboration, and Administrative Support

Physics professor Dan MacIsaac plays an indispensable role in guiding the intellectual development of the Buffalo State physics teacher education program. MacIsaac has been instrumental in developing the current form of the program, advocating for it, and incorporating the Modeling Instruction curriculum[1] in several courses. Both MacIsaac and Kathleen Falconer, a lecturer in Elementary Education and Reading, are nationally recognized experts on the use of the Reformed Teaching Observation Protocol (RTOP), a teacher assessment technique that is also used in the physics teacher education program. The physics department has also dedicated significant additional human resources to teacher education and professional development. At the time of the site visit, at least one-third of the regular physics faculty were associated with the program, and the department had recently hired a physics education researcher, Luanna Gomez, in a tenure-track position. Mac-Isaac, Gomez, and several adjunct faculty and other staff work together on both pre-service teacher preparation and in-service education.

Support for the program reaches the highest echelons of the institution. Both the president (now former president) and the provost indicated that the physics program is highly respected on campus and serves as a success story in interactions with external constituencies. The dean of education explicitly stated there was a significant collaborative effort among the deans, provost, and vice president to ensure the health of the teacher education programs.

Program Description

There are three paths within the overall physics teacher preparation program: undergraduate physics education, a post-baccalaureate certification-only program in physics education, and a Master's program in physics education. In addition, Buffalo State offers summer courses for in-service teachers pursuing a physics endorsement. The BSC program leverages the high interest in the graduate and summer program courses to offset the smaller number of undergraduate students who intend to teach physics. In that way, undergraduate students have access to many more specialized courses for teachers than would otherwise be possible.

New York State requires licensure for all physics teachers, which involves 30 credits of content courses. Six of those credits can be taken in a related field; therefore, effectively 24 credits are required in physics for a physics licensure. The BSC program includes two courses that combine Modeling Instruction (based on the Arizona State University program) and the Powerful Ideas in Physical Science curriculum, and the curriculum generally is infused with results from physics education research. Students also take a physics methods course and a number of education courses. Transfer courses from other institutions may be used to satisfy the physics content requirements.

The summer program of courses for those pursuing alternative certification is typically over-subscribed, and it generates significant revenue for the university. The summer workshops for in-service teachers form one of the largest programs for teachers of physics in the state. In addition, regular meetings at BSC during the school year provide professional development and community for in-service physics teachers.

1. See the link in the site visit report on Arizona State University for more details regarding the Modeling Instruction curriculum.

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Appendix C.5: City College of New York (New York City, NY)

The physics teacher preparation program at City College of New York addresses the needs of a large urban school system through a strong collaboration between the physics and secondary education departments.

Notable Features

- active collaboration between physics and secondary education departments; program champion has joint faculty appointment in both departments
- integration with the New York City Teaching Fellows program that recruits academically qualified graduates to teach as interns in high-needs schools
- a teacher preparation curriculum with graduate courses based on physics education research

Overview

The City College of New York (CCNY) works with a large, unified urban school system to help satisfy a need for qualified teachers. Within the CUNY (City University of New York) system, CCNY has a strong reputation as the school to attend for future science teachers. The physics department has about 30 faculty members, and graduates about 5 bachelor's and 5 master's students per year. The school of education has about 50 faculty serving three departments: childhood education, secondary education, and leadership and special education.

Approximately 60% of the participants in the teacher preparation program are also part of the New York City Teaching Fellows program; this program pays students for two years to teach as interns in high-needs schools while earning a teaching certification and master's degree. CCNY also has a master's program in the school of education that produces physics teachers. About half of all participants in these programs are older, non-traditional students, often attracted to teaching as a career change. In addition, undergraduate physics majors can get a teaching certificate by taking courses in the school of education. The Fellows program and the master's program together produce four to five physics teachers per year, while the undergraduate physics teacher preparation program produces only about one physics teacher every two years.

Leadership, Collaboration, and Administrative Support

Richard Steinberg is the program leader; he has a joint faculty appointment in the secondary education and physics departments. Multiple faculty and staff members from both departments are involved in physics teacher preparation. Steinberg has long been an active member of the physics education research community, and he spent a sabbatical year teaching physics in an urban high school in New York City. Steinberg also chairs a special task force created by the dean of sciences and dedicated to improving undergraduate education.

Collaboration between physics and education is built into the teacher preparation program. The dean of education asserted his own appreciation of the importance of deep content knowledge for teachers and said that he welcomes collaboration with the science departments. The dean of sciences said he plans to have two to three faculty members in each science department conducting discipline-based education research. (At the time of T-TEP's visit, each department had one such individual.) The dean already considers such research to constitute a legitimate part of the research agenda of each science discipline and is counted for promotion and tenure. These prospective future faculty members would also be involved in science-teacher preparation.

Program Description

The teacher preparation program at CCNY focuses on physics knowledge and knowledge of reformed teaching based on physics education research. Steinberg ensures that those certified in physics have adequate physics preparation, and he emphasizes the use of research-based instructional methods in introductory courses and in the physics teaching methods courses.

Students in the physics teacher preparation program follow one of three different paths:

- Undergraduate physics majors recruited through the physics department can take four courses (14 credits) in the school of education and complete a semester of student teaching (6 credits). These students would graduate with an undergraduate physics degree and an initial physics teaching certificate.
- Graduate students with an undergraduate physics major can complete a Master of Arts degree program for 35 credits. They do traditional student teaching, and graduate with a master's degree and a physics teaching certificate.

Fellows, who receive significant financial support, take the same credits as graduate students seeking physics certification. The Teaching Fellows program recruits academically qualified graduates who are prepared to enter as teachers in high-need disciplines, in high-need schools in New York City. In this two-year paid internship program, Fellows teach during the day and take classes at night and in the summer. Instead of traditional student teaching, however, Fellows do supervised teaching after the first summer, getting paid for their work in the classroom; they are assigned a mentor and supervisor from CCNY. The program also covers most tuition charges.

All physics teacher candidates are required to complete or have completed a bachelor's degree in physics (or the equivalent). Both through the course work and in the expectations of how graduates will teach, the program emphasizes a "student-centered inquiry-based approach to learning physics," as stated by the program leaders.

The physics teacher preparation program for master's degree students (including Fellows) includes two courses (six credits) that are focused on student development of knowledge in physics, analysis of the processes of science, and study of physics education research. These are offered as graduate courses in the department of secondary education. The program also includes a required Master's Project course (3 credits) in which teachers conduct research projects on student learning in physics. Future teachers learn state standards and testing requirements, and begin to understand the particular challenges of teaching in the New York City school system.

Undergraduate teacher-preparation students do not normally take the graduate-level "Development of Knowledge in Physics" courses taken by the Fellows and Masters certification students, but Steinberg tries to incorporate similar themes through special projects for these students, such as participation in physics education research work and/or co-authoring peer-reviewed papers and conference presentations.

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Appendix C.6: University of Colorado at Boulder (Boulder, CO)

The physics teacher education program at the University of Colorado at Boulder builds on the collaboration between physics and education faculty as well as on several ongoing education reform and research efforts.

Notable Features

- active collaboration between physics department and school of education
- early teaching experiences led by school of education and physics department
- institutional support up to the highest levels of university administration for STEM education initiatives, including physics teacher education

Overview

The University of Colorado at Boulder (CU-Boulder) has a large and thriving physics department with about 65 faculty members, 300 undergraduate majors (including physics, engineering physics, and astronomy), and 200 graduate students. Physics awards on average 45 bachelor's degrees per year, and has a track for undergraduate majors who want to become high school teachers. The School of Education has about 35 faculty members, who focus on teacher preparation and educational research. The university currently graduates an average of three physics teachers per year, a significant increase over previous years; the increase is attributed largely to the introduction of the Learning Assistant (LA) program. STEM education, including physics teacher preparation, has support from the highest levels of university administration. Teacher education also benefits from an active physics education research (PER) group with faculty in both the physics department and the School of Education. The group has championed education reforms and acquired substantial funding to support teacher education initiatives.

Leadership, Collaboration, and Administrative Support

Valerie Otero in the School of Education and Noah Finkelstein and Steve Pollock in the physics department, all of whom specialize in physics education research, form the core leadership for physics teacher education initiatives and other joint efforts between physics and education at CU-Boulder. Together, the physics department and the School of Education have received over $12 million in collaborative grants, all of which include a component in teacher preparation. The PER faculty are also central to a university initiative to build a campus-wide Center for STEM Education.

Physics department faculty value excellence in education and see this as a way to stand out among other departments at the university. In fact, the department has a tradition of putting the best instructors in their introductory courses, and has instituted a system of peer review of faculty teaching that is weighed in tenure decisions. The PER group has had a central role in the department for almost ten years; highly respected faculty members, including Nobel Laureate Carl Wieman, have engaged in education research, and a physics faculty member was recently granted tenure for his work in PER. The PER group has led successful efforts to reform the undergraduate curriculum, including both introductory and upper-level courses. Many of the reformed courses utilize Learning Assistants (LAs), who are peer instructors with pedagogical training who facilitate student learning in introductory courses. The LA program, which has now spread to dozens of campuses around the country, also serves as a powerful teacher recruitment tool.

University department heads, deans, and the Provost and Chancellor all strongly support physics teacher education. CU-Boulder has contributed several million dollars to support STEM education programs, and has developed innovative hiring practices and progressive standards for tenure and promotion of faculty who engage in science education research. Teacher education is tightly integrated into undergraduate STEM education through the LA program and other initiatives, which ensures greater visibility for teacher education within STEM departments, greater participation in content-specific teacher education among STEM faculty, and institutional sustainability.

Program Description

STEM students, including physics majors, are recruited to teaching through the Learning Assistant (LA) program, in which high-performing undergraduate students serve as peer instructors in transformed[1] introductory courses. LAs also take a concurrent pedagogy course that provides an introduction to the scholarship of teaching and learning. This early teaching experience, which takes place within disciplinary departments, allows students to "test the waters," and often sparks or confirms an interest in teaching. The experience also provides content-specific opportunities for students to develop knowledge about teaching and

1. LAs were originally instituted at CU-Boulder in the physics department in order to have enough facilitators to implement *Tutorials in Introductory Physics*, a research-based curriculum that requires students to work in small groups. Similarly, other research-based curricula with a strong emphasis on actively engaging students can benefit from the use of LAs, and LAs benefit from learning to teach with effective pedagogical methods.

learning. The LA program has helped raise the status of teaching within physics and other STEM departments.

The director of the LA program, Valerie Otero, plays a critical role in recruiting and advising future teachers. A network of faculty in physics and other departments refers students with an interest in teaching to Otero, and she encourages them to consider getting a teaching certification while completing their science major. She then tracks students through the teacher education program and helps them navigate the requirements. A retired physics teacher co-teaches the LA pedagogy course and provides students with first-hand knowledge of K-12 teaching based on personal experience. A former chemistry teacher was recently hired to co-direct the expanding program.

The new CU Teach program is part of a national effort to replicate the UTeach teacher education program at University of Texas at Austin. The CU Teach program enhances recruiting efforts by offering introductory courses with highly supported early teaching experiences in K-12 schools. CU Teach is the undergraduate certification program for secondary science and math teachers, and all education courses required for certification are focused on science and math. In addition to the undergraduate certification program, students who already have a bachelor's degree can get initial certification through the post-baccalaureate or masters programs.

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Appendix C.7: Illinois State University (Normal, IL)

The highly productive physics teacher education program at Illinois State University is housed in a physics department that has historically emphasized its teaching mission.

Notable Features

- program champion hired by the physics department specifically to run the physics teacher education program
- institutional context that encourages physics department engagement in physics teacher education
- sequence of courses focused on the teaching and learning of physics

Overview

Illinois State University (ISU) is a comprehensive regional university and former normal school with a reputation of being a good place in Illinois to become a teacher. The physics department places a larger emphasis on research than teaching, but has continued to embrace its role in teacher education. With 12 full-time tenured and tenure-track faculty members, the physics department annually graduates an average of 17 physics majors. ISU prepares a large number of physics teachers through its undergraduate program, recently growing from three such graduates in 2003 to nine in 2008. Preparation of physics teaching majors takes place primarily within the physics department, while the College of Education provides five generic "service" courses in secondary education. A large fraction of the program graduates become teachers and stay in teaching; based on a 2008 survey of 52 program graduates from 1995-2008, 87% were teaching at that time.

Leadership, Collaboration, and Administrative Support

The physics department has a firm commitment to physics teacher preparation, and hired Carl Wenning in 1994 as an instructional assistant professor to lead the physics teacher education (PTE) program. Wenning reformed and built the program into one of the largest in the U.S. His work was respected among the faculty, and his voice counted as much as any other during faculty meetings. When Wenning recently announced that he planned to retire, the department hired Kenneth Wester, a high-school physics teacher with over 20 years of experience, as Director of Teacher Education. Wester's commitment to reformed teaching and teacher preparation is the same as Wenning's, and thus the guiding philosophy of the program has been maintained. The department ensured a smooth transition between incoming and outgoing program leaders by allowing Wenning to stay on part-time until he fully retires. Richard Martin, the chair of the physics department, is committed to reformed teaching and both attends and presents at meetings of the American Association of Physics Teachers.

The current funding for 1.5 full-time positions for the staff to run the program and the dedicated space allotted to the program demonstrate overall administrative support, as does an encouraging and supportive attitude. As the chair of the department said: "If we need to cut positions, the physics teacher preparation program staff will be the last to go."

Program Description

The College of Education provides general education courses for the program, while all work related to student teaching and certification (including state-required paperwork) is the responsibility of the physics department. The teacher preparation program incorporates a large number of courses in which teacher candidates learn how to teach physics, and it also includes physics-related early teaching experiences prior to student teaching.

Students graduating from ISU's physics teacher preparation program receive a physics degree and a secondary-science teaching certificate with a designation in physics. They are certified by the state to teach all sciences, although their preparation is mostly in physics, and most of them do teach physics.

Recruitment to the program starts in high school through a wide network of contacts. Graduates of the program and teachers who participated in the Modeling workshops (see below) serve as recruiters, and the program director has produced colorful brochures and an active website about the program. The reputation of ISU as an institution that specializes in teacher education also helps attract students. Students at ISU, including a number of physics majors, have been recruited to the PTE program by other students who have good things to say about it.

The program director advises all physics majors who choose the teaching track and helps students navigate the list of requirements. PTE advisors maintain an "open door" policy so that students may have their questions answered on an informal basis at any time. The program leader teaches the physics methods courses and organizes teaching experiences, and has a great deal of contact with PTE students. A key feature of the program is the regular scheduling of Modeling workshops for in-service teachers, run by the program leaders; all PTE graduates are encouraged to participate in these workshops. This brings program graduates into the network of in-service teachers who practice Modeling, creating a community and helping them implement the curriculum.

To help teacher candidates learn how to teach physics, the physics department offers a coherent sequence of six physics teaching methods courses (totaling 12 semester hours). Specifically, the teaching methods course work focuses on inquiry teaching methods, science standards, lesson planning, technology, and history of physics. Teacher candidates read seminal papers in physics education, and also plan and teach a lesson in which their peers act as students.

The program provides multiple opportunities for teacher candidates to have physics-related classroom experiences in diverse contexts, including inner-city Chicago schools, a juvenile detention center, and University High School (in Normal, IL). These experiences follow the philosophy of cognitive apprenticeship: teacher candidates have an opportunity to observe expert teachers and interact with students, teach selected lessons, reflect on their practice, and finally engage in student teaching. Former program leader Carl Wenning used the term "sheltered environment" to describe ISU's pre-teaching classroom experiences. Program leaders make an enormous effort to ensure that students can practice what they have learned during student teaching. The program leader helps place student teachers, conducts classroom observations, and teaches a seminar course for student teachers. Overall, the ISU program is coherent and focused, and it provides teacher candidates with multiple opportunities to learn how to teach physics in a high school.

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Appendix C.8: University of Northern Iowa (Cedar Falls, IA)

The Physics Department at the University of Northern Iowa developed in-service physics teacher education programs that prepare teachers to earn state physics endorsements.

Notable Features

- institutional context that encourages physics department engagement in teacher education
- efforts to develop physics-specific pedagogical expertise of teachers
- programs designed for in-service teachers in small rural schools

Overview

The University of Northern Iowa (UNI) has emphasized teacher education for over 130 years. Its total student enrollment of 13,000 includes about 2,700 students who are majoring in some area of teacher education. Of the ten tenure-track faculty in the physics department, two (Professor Lawrence Escalada and Assistant Professor Jeffrey Morgan) specialize in physics education. UNI has produced physics teachers both through an undergraduate physics teaching degree track, and through externally funded summer institutes that enable in-service high school science teachers to obtain an endorsement to teach physics. The department graduates about seven physics majors per year, and on average less than one physics teaching major per year. However, the summer in-service institutes are the focus of this report.

Most school systems and high schools in Iowa are small; although most high schools offer physics, few science teachers teach only physics classes. The summer institutes have been effective in helping "retool" science teachers to become teachers of physics. Through the institutes, teachers are able to complete physics course requirements needed to receive a physics teaching endorsement from the state of Iowa. Recently, through two separate two-year institutes, 37 teachers have achieved this endorsement. The institutes fit into the teachers' schedules and budget (financial cost is minimal for participants due to external funding) and provide teachers with ongoing support during the school year to implement what they learn in the classroom.

Leadership, Collaboration, and Administrative Support

The success of the in-service program is due in large part to the intellectual and motivational leadership of Lawrence Escalada. In addition to in-service teacher training, Escalada focuses on curriculum development, and Morgan focuses on student learning in upper-level physics courses. They also teach general physics, physics for future elementary teachers, a general science methods course, and a methods course for physical science. Both Escalada and Morgan have high school teaching experience.

The physics education programs at UNI have succeeded because of effective connections within and beyond the physics department. The physics education faculty members are very much a part of the physics department (where their tenure and promotion are decided), and they are also active in the science education faculty, an inter-college, inter-departmental unit.[1] The physics department has strong connections with local districts, and the pre-service and in-service physics teacher education programs are responsive to the needs of Iowa schools regarding state requirements for physics teacher endorsement.

University administrators at all levels expressed strong support for the physics education programs. Production of quality teachers has long been central to the campus mission and culture. At the same time, the dependence on external funding introduces some degree of uncertainty regarding program sustainability.

Program Description

The UNI physics department has developed programs to enable in-service high school science teachers to earn an Iowa physics teaching endorsement. Previous programs incorporated two summer sessions (in 2002-2003 and 2006-2007, four weeks each summer) while a more recent program extended over three summers (in 2009-2012; two weeks each summer). In addition, after-school and weekend activities during the intervening and following academic years focused on physics content and pedagogical content knowledge. The programs have been funded by state grants with funds authorized through the federal No Child Left Behind program. The curriculum is built around PRISMS PLUS[2] and Modeling[3] NSF-funded curricula, both of which use active engagement in experimental investigations to introduce and apply fundamental physics principles.

Participants in past programs received up to 15 gradu-

1. The science education faculty is composed of subject-matter faculty in the disciplinary departments plus members of the Curriculum and Instruction Department in the College of Education, as well as members of the teaching faculty at the Price Laboratory School on the UNI campus.
2. The PRISMS curriculum for high school physics was developed at UNI in 1982 and revised and enhanced into PRISMS PLUS in 2005.
3. For more on Modeling, see the description of the program at Arizona State University.

ate credits in physics for the summer and academic-year courses. This meets the requirement for the Iowa physics endorsement, and the course work may also be applied toward a master's degree in science education at UNI. However, not all participants needed to complete the full program, since most had some previous physics preparation. Although the 2002-2003 program graduated 21 participants who received their physics endorsement, only 12 had completed the full two-year program. The 2006-2007 program graduated 16 participants who received an endorsement, while the 2009-2012 program is expected to graduate 31.

The institutes are highly coherent both pedagogically and with respect to the physics content. Since they focus specifically on the teaching of high school physics, they are directly relevant to the needs of the participants. Teachers are expected to implement what they learn, and institute faculty follow up with the teachers throughout the school year to determine what they learned and how well they are implementing it in their classrooms. Institute workshops and courses are taught by Escalada and Morgan in collaboration with experienced current and former high school physics teachers; these teachers have a high level of credibility among the participants.

Teachers remarked that their experiences with Modeling and PRISMS during the summer institutes taught them more physics than they had learned previously. They also remarked that these programs helped them feel comfortable with the physics they had learned, such that they felt they could do a good job of teaching these same concepts.

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Appendix C.9: Rutgers - The State University of New Jersey (New Brunswick, NJ)

Rutgers University has attracted national attention for a productive graduate program in physics teacher preparation, built on the development of specialized knowledge and skills for teaching physics.

Notable Features

- program champion with strong links to physics and education departments
- sequence of courses that is focused on the teaching and learning of physics
- rich intellectual community for graduates

Overview

Rutgers is a large, public, land-grant institution, drawing most of its students from within the state of New Jersey. The Department of Physics and Astronomy has over 60 faculty members and awards an average of 45 bachelor's, 6 terminal master's, and 13 Ph.D. degrees per year. The Graduate School of Education (GSE) focuses on teacher education, and well over half of the nearly 60 faculty members are involved in teacher education programs. The GSE offers five-year and post-baccalaureate programs that lead to both an EdM and certification. The GSE graduates about 100 secondary teachers per year. Secondary science education is split into two specialized programs including physics education, physical science education, and biological science education, which average 6 and 10 program completers, respectively, per year. Retention of graduates who become physics teachers is very high, and 49 of 54 graduates (90%) who entered the classroom since the program was reformed in 2001 are still teaching. Students in the physics teacher education program spoke enthusiastically about the intellectual rigor of the program, and felt that the physics-focused coursework was highly relevant and enjoyable.

Leadership, Collaboration, and Administrative Support

Eugenia Etkina, a GSE professor, is founder, director, and champion of the physics/physical science teacher education program. Etkina has an undergraduate degree in physics and a Ph.D. in physics education, and has 13 years of experience teaching middle school and high school physics. She is a nationally recognized researcher and NSF-funded curriculum developer.

Etkina collaborates with several members of the physics department, and works closely with the Director of Undergraduate Studies (DUS) to recruit and advise future physics teachers. The DUS also arranges for future teachers to be recitation or laboratory instructors in the algebra-based introductory physics course, a course that is taught by one of Etkina's former students. The research-based curriculum *Investigative Science Learning Environment* (ISLE) used in the course was co-developed by Etkina and a now retired PER faculty member in physics, Alan Van Heuvelen.

The GSE Dean expressed strong support for the discipline-specific education programs in physics/physical science and biological science. The physics/physical science program has five specialized courses in physics teaching methods with typical enrollments of 10 to 17 students. These students include pre-service teachers, in-service teachers seeking a graduate degree, and doctoral students in education.

Program Description

The Rutgers program is focused on the systematic development of pedagogical content knowledge (PCK), meaning knowledge of how to teach physics. Of the total 45 semester credit hours (9 of which are earned for the student teaching internship), 15 credits are devoted to PCK courses. These courses cover knowledge of students' prior understanding about and difficulties with key physics concepts and practices, knowledge of topic-specific instructional strategies in physics, and knowledge of what and how to assess with regard to students' understanding of physics concepts and practices. Through the five courses on physics pedagogy, future teachers develop these aspects of PCK for almost all physics concepts they will teach. They also deepen their understanding of physics, including physics content and the cognitive processes through which physics knowledge is developed.

Teaching experiences are closely integrated with coursework and occur every semester. During the first year, teacher candidates serve as recitation and/or laboratory instructors in a reformed introductory college physics course and spend 60 hours observing high school physics classrooms led by program graduates. A full semester of student teaching occurs in the fall of the second year, and student teachers are again placed with program graduates. They finish the final semester as recitation/laboratory instructors in the same course in which they taught during the first year. The same (ISLE) approach to learning physics is followed in all teaching experiences.

Graduates return to Rutgers for biweekly meetings where they receive coaching from the program director and assistance from their peers. The community extends to an active online discussion board. This active professional community is an important source of support for new teachers, and contributes to the high retention rate of program graduates.

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Appendix C.10: Seattle Pacific University (Seattle, WA)

Seattle Pacific University is a small, private institution that has a significant commitment to support physics teaching in Washington.

Notable Features

- smaller, active physics department specializing in physics education
- thriving Learning Assistant program to provide early teaching experiences in physics
- expert teachers engaged in recruiting, preparing and mentoring new teachers of physics

Overview

Seattle Pacific University (SPU) is a small, private, Christian university. The high priority on undergraduate education at SPU creates a supportive context for a thriving physics teacher education program. The physics department awards approximately five to six bachelor's degrees per year (there is no graduate program in physics). SPU awards an average of three to four physics endorsements per year through its various teacher certification programs.

The physics teacher education program grew out of the vision of John Lindberg, hired as physics chair over a decade ago during a major university initiative to improve its strength in the sciences. Lindberg made a strategic decision to concentrate on physics education, and hired several faculty in this area as positions became available. Currently, the physics department is engaged in elementary and secondary teacher education as well as a related program of research in physics education. There is a high priority on excellence in teaching, and courses are taught using research-based methods.

In 2006, SPU became a PhysTEC institution and received funds to improve its physics teacher preparation program. Since then it has received over six million dollars in grant funding to support teacher preparation and professional development programs.

Leadership, Collaboration, and Administrative Support

Several faculty members and expert teachers in the physics department work as a team to lead teacher education programs. Stamatis Vokos is a well-known physics education researcher and the intellectual leader of the physics education group at SPU. Lane Seeley leads the PhysTEC project and is involved with professional development efforts. Hunter Close[1] has been responsible for the Learning Assistant (LA) program,[2] which is the primary physics teacher recruitment effort. The Visiting Master Teacher (VMT), an expert physics teacher who works part-time with the secondary physics education program, provides physics-specific mentoring for student teachers and new teachers. Eleanor Close[3] has led the elementary teacher education effort, and had a joint appointment in both physics and education. She served as a key interface with the School of Education. Lezlie DeWater is a master teacher who teaches courses in physics content and physics pedagogy for prospective elementary teachers.

The university administration is very supportive of the work of the physics department. The dean of the school of education, the associate dean of teacher education, and the dean of the college of arts and sciences are all very knowledgeable of and connected to the physics teacher education program and are in regular communication with various physics faculty. In addition, the chair of the physics department is highly supportive of the physics education activities, and funding for the LA program comes from the physics department.

The physics department has developed a close working relationship with the school of education. In addition to the collaboration among the program leadership, a new tenure-track appointment in physics education was created in the physics department through a transfer of a full-time equivalent from the School of Education (this is the joint appointment formerly held by Eleanor Close). This was done in recognition of the physics department's high quality work in teacher education.

SPU has developed close ties with local school districts, and offers professional development on a regular basis for physics and physical science teachers. In partnership with Facet Innovations, an education research company, SPU has developed a formative assessment tool[4] widely used in the school districts. Through use of common assessments, a district-wide shared responsibility for the curriculum, and an emphasis on student learning, these schools have seen an increase in student performance in the physical sciences.

1. Hunter Close left SPU in 2011 to go to Texas State University at San Marcos.
2. For a description of Learning Assistants, see Appendix C.9: University of Colorado at Boulder.
3. Eleanor Close left SPU in 2011 to go to Texas State University at San Marcos.
4. For more information on this tool, see www.diagnoser.com

Program Description

SPU has several paths to certification and physics endorsement, offering a high degree of flexibility to meet the needs of students, including:

- an undergraduate program in which students can complete a physics degree and receive a secondary teaching certification and physics endorsement at the same time (4 years)
- a post-baccalaureate program in which students with a physics degree (or equivalent) receive secondary teacher certification and physics endorsement (15 months full-time[5])
- a Master of Arts in Teaching (MAT) program in which students receive a masters degree, teacher certification, and physics endorsement through mostly evening and on-line courses, allowing students to work full-time while completing the program (2 years part-time)
- a new Master's in Teaching Mathematics and Science (MTMS), based on the Alternative Route to Certification[6] program, which focuses specifically on the needs of math and science teachers (12 months for certification, 15 months total including the MTMS degree).

5. The post-baccalaureate program is 4 quarters during the academic year; it spans a 15-month time period with a summer off in the middle.
6. In the Alternative Route to Certification and MTMS programs, students are in K-12 classrooms every day during the school year and take courses during the evening, summer, and on-line, leading to teacher certification and an endorsement in physics (12 months full-time).

SPU's certification program consists of courses in topics such as educational psychology, diversity, general science methods, classroom management, and assessment. Certification also requires student teaching in schools. SPU provides support to graduates who are new science teachers in their first year of teaching, including content-specific mentoring, and guidance to help new teachers focus on student learning outcomes.

The Learning Assistant (LA) program at SPU is a key effort in recruiting undergraduates to become physics teachers. LAs work in transformed introductory physics courses to facilitate peer learning among physics students. Pedagogical courses specific to physics are offered for LAs and taught by the VMT, a former high school teacher who is openly supportive of teaching as a career track. The VMT also talks with students interested in teaching and interacts with LAs, so that students get to hear about teaching from a current physics teacher. In addition, there is a weekly department tea in which faculty and students can discuss career aspirations and other teaching-related issues.

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Appendix C.11: University of Washington (Main Campus, Seattle, WA)

The University of Washington has played a long-standing and significant role in physics education research, and in the development of curriculum materials and teacher education programs.

Notable Features

- program develops physics-specific pedagogical expertise of pre-service and in-service teachers
- sequence of courses focused on the teaching and learning of physics
- long-standing research and development program to create physics curriculum materials

Overview

The University of Washington (UW) is a large, research-intensive state university. The physics department has more than 40 tenured and tenure-track faculty and over 130 graduate students; it awards more than 50 bachelor's degrees each year. In 1979 it became the first U.S. physics department to award a Ph.D. in physics for research in physics education. The Physics Education Group (PEG) has been an integral part of the physics department since the early 1970s and is one of the largest physics education groups in the U.S. Since 1979, 23 graduate students in the Physics Education Group (PEG) have earned physics Ph.D.'s; in addition, more than 100 other graduate and undergraduate students have done research projects with the PEG. Faculty, graduate students, and K-12 teachers from all over the world have visited the group and participated in its programs.

Pre-service and in-service teacher preparation has been a major focus of the Physics Education Group for more than 40 years. The program has both academic-year and summer components which are devoted to physics, housed in the physics department, and taught by physics faculty. The teacher education courses are closely linked to the group's research in physics education. Instruction is based on Physics by Inquiry (Wiley, NY, 1996), which is a research-validated curriculum developed by the PEG for the preparation of elementary and secondary teachers.

Leadership, Collaboration, and Administrative Support

The key leaders in the physics teacher education effort have been Lillian C. McDermott, Paula Heron, Peter Shaffer, MacKenzie Stetzer, and Donna Messina. McDermott, Heron, and Shaffer are physics professors at UW, and Stetzer was a research assistant professor.[1] Messina, a former middle- and high-school teacher with a Ph.D. in Education, has served as a master teacher in the summer programs and in the academic-year courses. All the physicists play a prominent role in the national and global PER communities. The Physics Education Group received the 2008 American Physical Society "Excellence in Physics Education Award" for its long-standing leadership in physics education research and development.

The group's annual programs, "Summer Institutes in Physics and Physical Science for Inservice K-12 Teachers," have been funded by NSF, which has also supported research and curriculum development by the PEG. The UW physics department has allocated three faculty positions to the group, as well as substantial space, several graduate teaching assistantships, and some administrative help. Blayne Heckel, the Department Chair, reported that the University of Washington views the Physics Education Group as a "pillar of excellence."

Program Description

Since the early 1970's, physics education research has had a major impact on teacher preparation at the University of Washington. Physics by Inquiry (PbI), a self-contained, laboratory based curriculum developed by the PEG, is used in both pre-service and in-service teacher education. Teachers working together in small groups conduct experiments on a wide variety of physical systems, and analyze and discuss the outcomes. Guided by questions posed by the instructional staff, they develop physical models to predict and explain the behavior of the systems under investigation. PbI is designed to strengthen the teachers' subject-matter background by developing both reasoning skills and conceptual understanding.

The Physics Department offers a three-quarter sequence of courses during the academic year for pre-service teachers, with a typical enrollment of ten to fifteen students. Some plan to become high-school teachers of physics and other sciences, while others are undergraduates or graduate students in the Master's in Teaching (MIT) program. All three academic quarters are required for MIT students seeking a physics endorsement. About three students per year receive a physics endorsement through UW. There have also been special courses for elementary and middle school teachers; these are not currently offered, but the PEG hopes to revive them.

Most physics teacher education by the PEG takes place

1. Stetzer was at UW until 2011, when he became an assistant professor in the physics department at the University of Maine.

during the annual five- or six-week NSF Summer Institutes for Inservice K-12 Teachers. Typically, about 20 participants are high school teachers and about 10 are middle school teachers, with fewer at the elementary grades; about two-thirds of the teachers are from the state of Washington. Usually, about half are first-timers; the others are returning for a second or third year. (Since the program content is rotated each year on a three-year cycle, participants are allowed to attend for up to three years.) The Institutes are closely tied to the doctoral program in physics education research. Ph.D. students in PER are on the instructional staff for the Summer Institutes, in which they develop and test new curricular materials.

Associated with the Summer Institutes is a Continuation Course that meets weekly all three quarters of the academic year. All local teachers who have participated in one or more Summer Institutes are encouraged to attend. Typically, 10 to 25 teachers enroll each quarter, about half of whom are high school teachers. They continue to learn new physics topics through inquiry, apply what they have learned as they plan lessons for their classes, and participate in discussions with one another and with the instructional staff. The program helps teachers deepen their understanding of physics and of inquiry-based pedagogy. Physics content is the main focus, but inquiry-based pedagogy and the nature of science are implicitly addressed and are discussed more explicitly in the Continuation Course. This course is especially helpful to teachers in other STEM disciplines seeking a teaching endorsement in physics. Some teachers participate in the Summer Institutes and Continuation Courses to strengthen their physics background before they take the required state certification exam. (This exam constitutes the sole requirement in Washington State for experienced out-of-field science teachers who seek a physics endorsement.) Perhaps the most important benefit of the Continuation Course is the creation of a vibrant professional learning community.

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Resources for the Education of Physics Teachers

David E. Meltzer, lead author

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Transforming the Preparation of Physics Teachers: A Call to Action

The Task Force found that, except for a handful of isolated models of excellence, the national landscape of the professional preparation of physics teachers shows a system that is largely inefficient, mostly incoherent, and completely unprepared to deal with the current and future needs of the nation's students. Physics departments, schools of education, university administrators, school systems, state agencies, and the federal government, along with business and foundations, all have indispensable collaborative roles to play so that *every high school student has the opportunity to learn physics with a qualified teacher.*

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