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

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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.

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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]

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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 Academy of Sciences, *Physics: Survey and Outlook* (National Academy of Sciences, National Research Council, Washington, D.C., 1966), p. 747. 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 Phys*ics **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]

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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 1* (National Academy of Sciences, Washington, D.C., 1972), pp. 27-30.

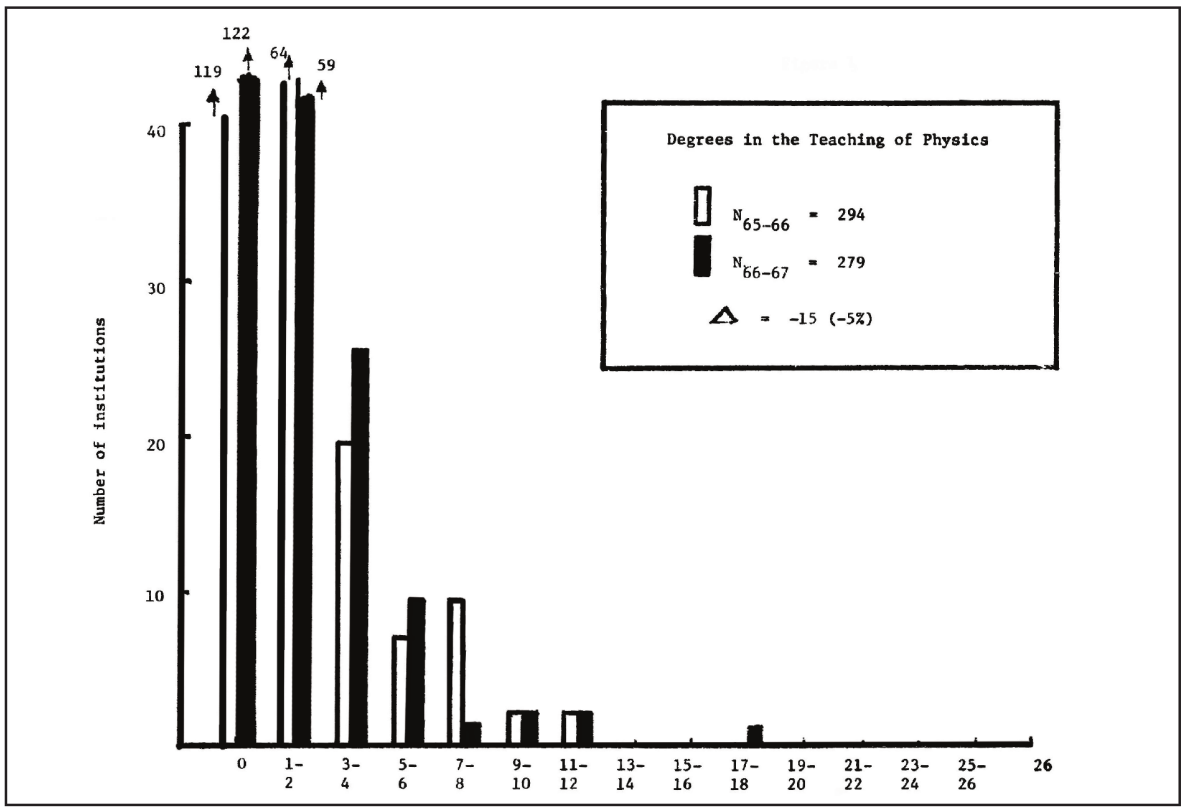

Figure 8. Distribution of physics teacher graduates from U.S. institutions, 1965-1967. Source: See Ref. 26 on p. 34.

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).