How Should Physics Teachers Be Prepared? A Review of Recommendations

Cite as: Phys. Teach. **59**, 530 (2021); https://doi.org/10.1119/5.0022299
Published Online: 24 September 2021

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Many readers of this journal are probably familiar with calls from governmental, business, and educational authorities to expand and improve the preparation of science teachers, with a particular focus on the shortage of highly qualified physics teachers. It may seem as if this problem has been around forever, and in fact similar expressions of alarm have been heard for well over a century. Why, then, does this shortage persist? Has the physics community been negligent in offering possible solutions? In fact, the opposite is true: physics educators long ago arrived at a consensus and pointed to a way forward, with a consistent set of recommendations. By tracing the history and elucidating those recommendations, we hope to help motivate physics educators to promote these goals more clearly, and with greater specificity and urgency.

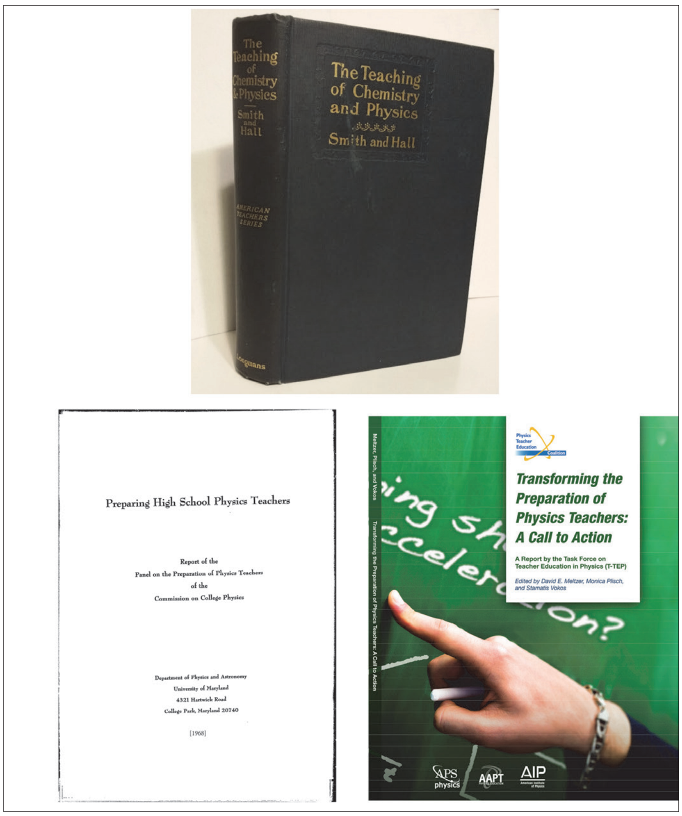

Fig. 1. Physics teacher preparation has been a subject of interest for over a century. Top center, 1902 book by A. Smith and E. H. Hall; left, 1968 report by the Commission on College Physics; right, 2012 report by the Task Force on Teacher Education in Physics.

Introduction

From the early days of high school physics instruction in the U.S., there was discussion and debate regarding instructional methods and how best to prepare teachers proficient in those methods (see Fig. 1).[1] In 1884, a survey showed that U.S. physics teachers strongly favored "inductive" methods of instruction utilizing laboratory activities, and the accompanying report highlighted the challenges of preparing teachers who could teach in this manner.[2] In 1893, the National Educational Association (NEA) "Committee of Ten" recommended laboratory-based science instruction for all high school students.[3] In 1920, the NEA recommended that physics teachers should learn to guide students in solving problems arising from everyday experiences, utilizing "projects" and laboratory investigations.[4] (The theme of increasing student interest by relating investigations to everyday experiences had been a focus of the 1906 "New Movement Among Physics Teachers" led by Chicago professor C. R. Mann, and was discussed extensively in Mann's 1912 book on the teaching of physics.[5]) In 1932, the "Yearbook Committee" of the National Society for the Study of Education (NSSE) emphasized the need for strong content-knowledge preparation of physics teachers.[6] In 2012, following a four-year investigation, a report was released by the Task Force on Teacher Education in Physics (T-TEP), a group jointly funded by the American Physical Society, the American Institute of Physics (AIP), and AAPT. Findings and recommendations in this 2012 report were highly consistent with those in previous reports, ranging back to the 1880s.[7] Some of the main themes of the recommendations in these reports follow below. Our focus here is primarily on recommendations for physics teacher *preparation*, while further discussion of recommended teaching methods is left for the references; see, in particular, those cited in Ref. 1.

Principal recommendations for physics teacher education

1. Thorough preparation with deep content knowledge is necessary

Almost since physics teaching began in the U.S., the need for deep physics content knowledge has been at the forefront of recommendations for physics teachers. In 1884, reporting on his national survey on the teaching of physics, C. K. Wead outlined the fundamental issues in physics teacher education in a manner that would probably be embraced by most physics educators who were to follow:

> …[T]he teacher should have a knowledge far exceeding the amount he must teach, a training in methods of teaching, and a manual skill in making and using apparatus that is called for in scarcely any other subject; otherwise mistakes in method and fact will be common in his teaching and his instruction will be a constant appeal to the text book or other authority, thus losing the very thing that is of peculiar value in the training derived from the study of the sciences. In such cases little information is really gained or retained, and as the study is not vitalized by an appeal to nature the phenomena are not understood or are misunderstood, and the results for good are slight; even the time may be

 DOI: 10.1119/5.0022299

worse than wasted, for it is difficult for future teachers to undo the harm of bad training.[8]

This theme was synthesized by Wead from responses to questionnaires sent to dozens of high schools, colleges, and "normal" (teacher-training) schools; with relatively minor variations, it has been consistently reiterated by physics educators during the 137 succeeding years.

In 1909, at a meeting of physicists discussing the relation between colleges and secondary schools, a majority endorsed the recommendation that prospective high school physics teachers should have preparation equivalent to that of graduate students who were beginning their thesis research.[9] The 1932 NSSE Yearbook Committee, though composed of general science educators who were not physics specialists, stated explicitly that physics students are handicapped in achievement "when their teachers lack a thoroughly adequate background of subject matter…."[10] In 1960, the American Association for the Advancement of Science (AAAS) reported that their "Cooperative Committee on the Teaching of Science and Mathematics" recommended 20 to 24 semester hours in physics as minimum preparation for physics teachers,[11] while a 1968 AAPT/AIP Committee recommended a minimum of 24 semester hours, or 18 hours plus "in-service training"; this recommendation was reiterated in 1972.[12] In 1988, the AAPT affirmed that high school physics teachers should have preparation equivalent to that of a physics major, although more flexible wording has been adopted in recent recommendations.[13] In its 2009 booklet on the qualifications of secondary school physics teachers, AAPT described the specific areas of knowledge needed by a teacher while stating that "ideally, physics teachers will learn this content through a major in physics." They recommended that teachers without adequate content preparation should take "one or more physics teaching methods courses."[14] In this regard it is worth noting a careful and influential study carried out by Hughes in 1925; he found that high school physics students with the highest test scores had teachers who had completed a physics major.[15] (Ironically, despite the vast expansion of research into physics education over the past 95 years, it does not seem that anyone has attempted to replicate Hughes's study.)

2. Prepare teachers to teach through "inquiry"

It is remarkable that a need for preparation in teaching physics by "inquiry," an oft-cited theme that is sometimes thought to be more modern than that of mere content knowledge, is in fact just as venerable as the latter. Learning by inquiry may be loosely characterized as an emphasis on learning through the inductive method, often via hands-on experimentation. It was well characterized by Wead in 1884, in a manner that would be acceptable to many present-day practitioners; he wrote that

> the weight of opinion is decidedly that at first the teaching should be inductive … [although]. … the teacher has probably known little or nothing of it in his own [college] education… .
>
> [In inductive teaching,] although the principles and laws are stated, the experiments have preceded them; many questions are asked in connection with the experiments that tend to make the student active, not passive, and allow him to think for himself before the answer is given, if it is given at all.[16]

This theme, too, has been stated and restated with remarkable regularity during the past century. For example, in his 1902 textbook written for prospective and practicing physics teachers, Harvard's Edwin H. Hall stated:

> I would keep the pupil just enough in the dark as to the probable outcome of his experiment, just enough in the attitude of discovery, to leave him unprejudiced in his observations, and then I would insist that his inferences…. must agree with the record… of these observations…. the experimenter should hold himself in the attitude of genuine inquiry.[17]

In 1920, George R. Twiss, the chair of the NEA Physics Committee, said that prospective teachers must "approach all their teaching problems inductively," and that college science teachers must "foster in prospective teachers the inductive rather than the cock-sure habit of mind." He added,

> The student can get real command of a general principle only when he has arrived at it inductively through a considerable number of concrete cases, out of which he has analyzed the general principle through his own mental processes. He must have perceived in the various concrete cases the common features which the general principle describes; else he can have no real command of the principle. Until he has arrived at it inductively, it remains an item of belief, perhaps; but it cannot be an item of knowledge. So it is of fundamental importance that his teacher shall so direct him that he must do this inductive thinking himself. The crucial test of his success is ability, first to state the principle in his own words.…[18]

The 1947 NSSE Yearbook Committee also emphasized a need for physics teachers to put emphasis on inductive methods of instruction.[19] In 1968, the AAPT/AIP committee advocated courses for teachers using the "learning by discovery" method:

> 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.…[20]
>
> The instructor should guide the students to devise methods of seeking answers to their own questions.[21]

In 1973, the National Academy of Sciences Physics Survey Committee said that "successful use of inquiry-directed instruction requires teachers who have themselves learned to investigate in this manner" and advocated "courses conducted in the inquiry mode and intended for elementary and secondary school teachers."[22] The 2009 AAPT booklet, referred to above, also strongly emphasized a need for physics teachers to focus on "scientific inquiry."[23] Dozens of similar statements can be found in a multitude of reports published during the past 137 years.[24] Present-day "modeling instruction" also makes use of this approach.

3. Create special courses for physics teachers

Another common theme is that special college-level courses should be taught specifically for prospective physics teachers, preparing them not only in physics content but also in physics pedagogy. For example, in 1884, Wead noted that "training … in teachers' classes at colleges aims … largely to give a knowledge not only of facts and their presentation but of the points of special difficulty…."[25] In 1960, a "Joint Commission" united scientists and teacher educators in recommending a second-year physics course, "preferably specially planned for the teacher."[26] In 1972, the AAPT/AIP committee recommended 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.[27] In 1973, the Physics Survey Committee of the National Academy of Sciences advocated "widespread introduction of courses… intended for elementary and secondary school teachers."[28] The 2012 T-TEP report recommended inclusion in the teacher preparation program of at least one course on the learning and teaching of physics.[29]

Recommendations viewed in the light of recent research findings

Most of the recommendations enumerated above were not based on systematic research findings. However, a substantial amount of research in physics teacher education has been carried out during the past 30 years, and the findings are broadly consistent with the experts' recommendations. A detailed review of this research is available elsewhere, but here I summarize the key findings[30]: (1) Pre- and in-service physics teachers often underestimate and/or do not address their students' ideas and "alternative conceptions" in physics, implying a need for content-focused pedagogical instruction; (2) Pre- and in-service physics teachers both require and value close, extended supervision by expert physics teachers as they develop structured lab activities that emphasize designing of experiments, deducing principles from observational data, and making predictions based on those principles; (3) Special courses on physics concepts and pedagogy for teachers have often been shown effective in improving their physics content understanding and/or physics teaching practices, as well as their students' learning.

Statistical trends in physics teacher preparation in the United States

In order to compare and contrast the actual situation with the "ideal" recommendations cited above, I will briefly summarize some statistical data reflecting trends in physics teacher preparation in the United States.

1. Most U.S. physics teachers have less content-matter preparation than recommended

The available evidence suggests that most U.S. physics teachers have now—and have always had—less than the recommended physics preparation cited above, that is, a major or minor in physics, or the equivalent (~24 semester hours). Average preparation has increased substantially over the years, but more than 50% of teachers still fall short of that target. Although no national surveys regarding this figure are known before the 1960s, many pre-1950 statewide surveys are quite consistent with a figure of 20% or less meeting the 24-hour standard.[31] In 1961, a nationwide survey found that only 33% of physics teachers had 18 or more credit hours in the subject,[32] while American Institute of Physics surveys of physics teachers in 1993 and 2013 found that only 45% and 40%, respectively, had a major or minor in physics or physics education.[33] The findings of the T-TEP survey were also consistent with this conclusion.[34]

Part of the problem lies in state teacher certification requirements that rarely require physics teachers to have the preparation recommended by the physics community; teachers who have a major teaching field outside physics are usually allowed to teach physics courses with few or even no college credits in physics.[35] However, even in states that do actually require, on paper, that physics teachers have the recommended 24 semester hours, various "emergency certification" rules and other workarounds are often invoked to allow teachers with weak physics backgrounds to add physics classes to their teaching loads.

2. Physics teachers are expected to spend much of their time teaching other subjects

In the 1920s, surveys showed that most teachers of physics (as well as many other individual subjects) taught two, three, or more other subjects.[36] As late as 1961, more than 80% of U.S. physics teachers spent the majority of their time teaching other subjects.[37] In fact, most physics teachers taught a predominantly non-physics program until 2009.[38] In part, this is a recognition that most present-day U.S. physics teachers are specialists in another subject, but not in physics. It is also an acknowledgment that the depth of knowledge associated with physics specialization is simply not an expectation that most school or district administrations have for their teachers of physics—for better or for worse.

3. Specialized courses for U. S. physics teachers are rare

During the early 1900s, many teachers' colleges (current and former "normal schools") offered courses on physics pedagogy; findings of a 1927 study suggest that 20 to 40% of these schools may have offered such courses.[39] A number of state colleges and universities also offered such courses, as well as occasional summer-session lab-based "physics for teachers" courses. (Future Nobel laureate R. A. Millikan taught a summer course called "The Pedagogy of Physics" at the University of Chicago in 1910.) Little is known about the content of the pedagogy courses beyond brief course descriptions printed in the college catalogs. However, we can deduce that enrollments were apparently quite low, since extremely few "trained" physics specialists were produced.

For example, an intensive physics teacher education program existed at Columbia University Teachers College in New York City for over 25 years. Originated in 1889 by nationally known physics educator J. F. Woodhull, the program at times included multiple advanced courses in physics teaching. Students could obtain a variety of credentials certifying their qualifications to teach physics (or "physical science," when combined with chemistry), for example, a "secondary diploma" and, for more advanced students, a "higher diploma" or a "master's diploma." However, even at this prestigious institution, the actual number of students who received physics or physical science credentials was extremely small, typically five or fewer each year, according to the lists of degree candidates and graduates printed in the annual college bulletins. For example, in the 1900-01 Teachers College Announcement, there were two candidates listed for the higher diploma in physics, and two for the secondary diploma; in the Announcement for 1910-11, there was one candidate for a doctor's degree in education with a minor in physics, as well as one for a master's degree with the same specialization.[40]

As normal schools disappeared from the scene—in many cases, transforming into state colleges and state universities under a new name—physics teacher education increasingly came into the hands of physics departments and university colleges of education. Although some of these departments and colleges did and still do offer specialized courses for physics teachers, T-TEP found little evidence that such courses are at all widespread at the present time. Specifically, after surveying almost 600 physics departments, only a few dozen were found to offer any physics pedagogy courses of any type, and most of these were single courses with extremely low enrollment.[41]

4. Physics teacher education programs in the U.S. are scarce and produce few graduates

Complaints about the shortage of qualified high school physics teachers have been prevalent from the earliest days of physics teaching up until the present day; these complaints were occasionally combined with expectations that the situation was improving. For example, 1881: "…the difficulty of finding trained teachers or teachers with whom science was not subordinate to other things…. is real enough, although it is rapidly dying away…"; 1946: "[There is] a deficiency in the number of well-trained science teachers in the secondary schools"; 1966: "…there is a short supply of physics teachers at every educational level…. [there is a] shortage, or even absence, of competent physics teachers in many secondary-school systems"[42]; 1968: "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 10 of the schools surveyed graduate more than five physics teachers per year..."[43] [emphasis in original]. A recent study has found that 50 years later, this situation is virtually unchanged. Most institutions graduate zero or one physics teacher each year, with only a tiny handful graduating more than four. A bar chart representing this distribution in the mid-1960s[44] appears virtually identical to the one created in 2012 by T-TEP to represent their findings regarding the current situation.[45]

Conclusion

In recent years there have been some notable positive developments in physics teacher education,[46] but it is still the case that the vast majority of U.S. physics teachers are prepared outside of physics departments and without the benefit of any systematic physics teacher preparation program.[47] Although one can debate whether or not this is a desirable state of affairs—or, if not desirable, perhaps unavoidable—this paper demonstrates that physics disciplinary specialists have long preferred an approach to the preparation of high school physics teachers that differs substantially from the one that currently prevails.

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