What does it mean to be a well-prepared physics teacher?

As a partial answer to this question, we offer two distinct responses: (I) the recommendations made by the physics education community over the past century, which, though based more on judgment than on research, have been quite consistent over the years; and (II) what we have learned so far from published research on physics teacher education.

I. Three themes have been stressed consistently since the 1800s by those engaged in the professional preparation of physics teachers; these are: (1) deep content knowledge is necessary; (2) teachers should be prepared to teach by "inquiry," meaning by engaging their students in investigations aimed at deducing physical principles from experimental observations and data; and (3) special courses designed specifically for prospective physics teachers should be made available to them.

Regarding (1): The consensus recommendation since the 1940s is that physics teachers should have preparation equivalent to a physics major or minor, roughly equal to 24 or more credit hours of study. In cases where that is lacking, additional professional development should be added. The justification for this recommendation was stated as well as ever by Prof. C. K. Wead in 1884:

> …the [physics] 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 worse than wasted, for it is difficult for future teachers to undo the harm of bad training.[1]

Regarding (2), a characterization of what we today call "inquiry" teaching (and was previously known as "inductive" teaching) was also stated with clarity by Wead in 1884, as follows:

> …[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.[2]

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[1] Charles K. Wead, *Aims and Methods of the Teaching of Physics [Circulars of Information of the Bureau of Education, No. 7—1884]* (Washington [DC]: Government Printing Office, 1884), 125.

[2] Wead, *Aims and Methods of the Teaching of Physics*, 117-122.

In 1902, E. H. Hall described his own implementation of the "inquiry" method:

> 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.[3]

As far as *why* physics teachers should be prepared to teacher in this manner, an explanation was offered by Prof. George Twiss in 1920:

> 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…. [4]

Regarding (3), Wead noted in 1884 that courses for prospective teachers aim "largely to give a knowledge not only of facts and their presentation but of the points of special difficulty…."[5], the latter being a crucial topic that is *not* covered in any courses in the ordinary physics major curriculum. Moreover, it has been repeatedly noted that methods of teaching physics by inquiry are nowhere to be found in the standard physics curriculum, and so require targeted instruction most efficiently accomplished in separate courses for physics teachers. Specific recommendations for such courses have been repeated by various committees and reports in 1960, 1968, 1973, and most recently by T-TEP in 2012.[6]

A vast number of additional citations in support of these recommendations—made by physics educators over the years—can be found in the T-TEP report.

II. It has proved very challenging, for a variety of reasons, to demonstrate conclusively through research the actual effectiveness of these or any other recommendations for physics teacher preparation. However, a substantial amount of research in physics teacher education has been carried out during the past 30 years, and the findings are

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[3] Edwin H. Hall, 'The Teaching of Physics in the Secondary School', in Alexander Smith and Edwin H. Hall, *The Teaching of Chemistry and Physics in the Secondary School* (New York: Longmans, Green, 1902), 278.

[4] G. R. Twiss, 'The Reorganization of High School Science', *School Science and Mathematics* 20 (1920): 1-13.

[5] Wead, *Aims and Methods of the Teaching of Physics*, 125.

[6] Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), 25.

broadly consistent with the experts' recommendations. A detailed review of this research is available elsewhere, but here we summarize the key findings:[7]

(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 and extended supervision by expert physics teachers as they plan and implement 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.

[7] David E. Meltzer, 'Research on the Education of Physics Teachers', in *Teacher Education in Physics: Research, Curriculum, and Practice*, David E. Meltzer and Peter S. Shaffer, eds., (College Park, Maryland: American Physical Society, 2011), 3-14.