Research on U.S. Physics Teacher Education

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Outline

- Historical overview: U.S. physics teacher preparation
- Consensus recommendations for teacher education by U.S. physics community
- Outcomes and findings of research on U.S. physics teacher preparation

Early Days (Before 1900)

- Fewer than 5% of all high-school age students actually graduated from high school
- Nearly all high school graduates took physics
- Physics was commonly required for college admission
- Most (> 90%) high schools were very small and did not have specialist physics teachers

Modern Times (≈1900-1950)

- Explosive increase in proportion (to > 50%) of all high-school age students who actually graduated from high school
- Elective system introduced: Less than 30% of high school graduates took physics
- Physics was no longer commonly required for college admission
- Many (> 90%) high schools were *still* very small and did not have specialist physics teachers

Primary Constraints

- Persistent large proportion of very small schools
- Physics taught only as one-year course, for third- or fourth-year students (no gradual “easing in” to college-prep physics courses in early grades)
- College and high school requirements for physics were (mostly) eliminated around 1900
- *Never* any steady supply or systematic production of well-prepared teachers

Primary Outcomes

- Most physics teachers taught multiple subjects, had primary background in subjects other than physics.
- Educational system at all levels K-20 developed high tolerance for low average effectiveness of high school physics teaching (e.g., prevalence of out-of-subject teachers, low weighting of physics learning outcomes, college courses assuming little preparation).
- Despite 100 years of warnings and admonitions, no real emphasis was ever placed on the necessity of teachers who have both deep physics content knowledge and preparation, ability, and desire to guide students in extended hands-on investigations.

Consequences

- No generally accepted “system” of physics teacher education ever developed in the U.S.
- Very few U.S. teacher education programs ever focused on physics teachers.
- Most teachers of physics in the U.S. never prepared specifically to teach physics.
- There has been a perceived shortage of well-prepared physics teachers continuously since 1880.

Key Historical Events: I

- **1884:** Survey shows U.S. physics teachers strongly favor "inductive" method of instruction utilizing laboratory activities
- **1893:** National Educational Association (NEA) "Committee of Ten" recommends laboratory-based science instruction for all high school students
- **1920:** NEA recommends that physics teachers learn to guide students in solving problems arising from everyday experiences, utilizing "projects" and laboratory investigations
- **1932:** "Yearbook Committee" of National Society for the Study of Education emphasizes need for strong content-knowledge preparation of physics teachers

Key Historical Events: II

- **1939:** AAPT forms “Committee on the Teaching of Physics in Secondary Schools” (CTPSS).
- **1946:** CTPSS reports on “deficiency in the number of well-trained science teachers.” It endorses cooperation between physics and education departments, including joint supervision of practice teaching by pre-service teachers.
- **1947:** First summer institute for in-service physics teachers, sponsored by General Electric, held at Case Institute of Technology
- **1955:** First NSF-sponsored summer in-service institutes for physics and chemistry teachers

Key Historical Events: III

- **1956:** AAAS joins with American Association of Colleges for Teacher Education to form “Joint Commission on the Education of Teachers of Science and Mathematics.”
- **1960:** AAAS Joint Commission recommends that institutions preparing science teachers should form teacher education committees of scientists, science teachers, and educators.
- **1966:** Physics Survey Committee of National Academy of Sciences cites “severe educational crisis for physics” in the high schools, links it to shortage of competent high school physics teachers.
- **1966:** Commission on College Physics forms “Panel on the Preparation of Physics Teachers” (PPPT).

Key Historical Events: IV

- **1968:** Following extensive investigation, PPPT issues report "Preparing High School Physics Teachers":

  "Most of our present high school physics teachers are unprepared to teach physics.…the shortage of qualified high school physics teachers is one of the most pressing problems facing American physics today...."

- **1972:** PPPT issues updated edition of report; states:

  "…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."

- **1973:** Physics Survey Committee of the National Academy of Sciences issues new report, states that institutions should take active role in providing workshops, summer programs, and other resources for practicing physics teachers.

Key Historical Events: V

- **2012:** Following four-year investigation, release of report by Task Force on Teacher Education in Physics (T-TEP)

  [joint project of American Physical Society, American Association of Physics Teachers, and American Institute of Physics]

  – Findings and recommendations consistent with those of previous reports

Common Themes I:
Deep Content Knowledge is Necessary

- **1884:** "…the teacher should have a knowledge far exceeding the amount he must teach…otherwise…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." [Wead, p. 125]
- **1909:** Physicists recommend that teacher preparation should be at level of graduate student in physics
- **1932:** Yearbook Committee states that physics students are handicapped in achievement "when their teachers lack a thoroughly adequate background of subject matter…."
- **1960:** AAAS recommends 20-24 semester hours minimum

Common Themes II:
Special Courses for Physics Teachers

- **1884: "…**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…." [Wead]
- **1960:** AAAS recommends second-year physics course, "preferably specially planned for the teacher"
- **1968:** PPPT recommends 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.
- **1973:** Physics Survey Committee (National Academy of Sciences) advocates "widespread introduction of courses… intended for elementary and secondary school teachers."

Common Themes III:
Prepare Teachers to Teach Through Inquiry

- **1884:** The “weight of opinion is decidedly that at first the teaching should be inductive” but “the teacher has probably known little or nothing of it in his own education”; “…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.” [Wead]
- **1920:** NEA Physics Committee Chair says “prospective teachers must approach all their teaching problems inductively….college science teachers must foster in prospective teachers the inductive rather than the cock-sure habit of mind.”

Common Themes III (continued):
Prepare Teachers to Teach Through Inquiry

- **1968:** PPPT advocates courses using “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….The instructor should guide the students to devise methods of seeking answers to their own questions.”
- **1973:** Physics Survey Committee says “successful use of inquiry-directed instruction requires teachers who have themselves learned to investigate in this manner” and advocates “courses conducted in the inquiry mode and intended for elementary and secondary school teachers.”

"…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….

"…Twenty years ago the difficulty would have been to secure competent teachers. To-day this want is being met by the extension of scientific studies at the colleges, by improvements in the work of the normal schools, and by the establishment of Summer courses of study…. Every year the number of teachers competent to give laboratory instruction is greatly increased, and before long the supply will be equal to any demand which is likely to arise."

F. W. Clarke, *A Report on the Teaching of Chemistry and Physics in the United States* (1881), p. 11; p. 19

“Many of the replies emphasize the difficulty of getting proper teachers for this subject, both for the schools and for the colleges; for the 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…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…the time may be worse than wasted, for it is difficult for future teachers to undo the harm of bad training….

“But as the demand for better teachers increases the supply will increase….”

C. K. Wead, *Aims and Methods of the Teaching of Physics* (1884), p. 125.

“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….”

G. R. Twiss [Chairman of NEA Physics Committee on Reorganization of Science in Secondary Schools] (1920)

Excerpts from *Preparing High School Physics Teachers* (1968):

"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…." [p. 5]

Excerpts from *Preparing High School Physics Teachers* (1968):

"…the shortage of qualified high school physics teachers is one of the most pressing problems facing American physics today…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...." [p. 5]

Does a Teacher's Physics-Major Background Make a Difference?

Hughes (1925) compared students' performance on a common physics test for four groups of teachers:

I: no college physics

II: one year of college physics

III: two years of college physics

IV: with physics major

(Note: No significant differences in students' IQ or years of teaching experience among the four groups)

Does a Teacher's Physics-Major Background Make a Difference?

Result:

- Students with highest test scores had teachers who had completed a physics major
- Students whose teachers had one or two years of college physics did (slightly) worse than those who teachers had no college physics

[J.M. Hughes, School Review **33**, 292 (1925)]

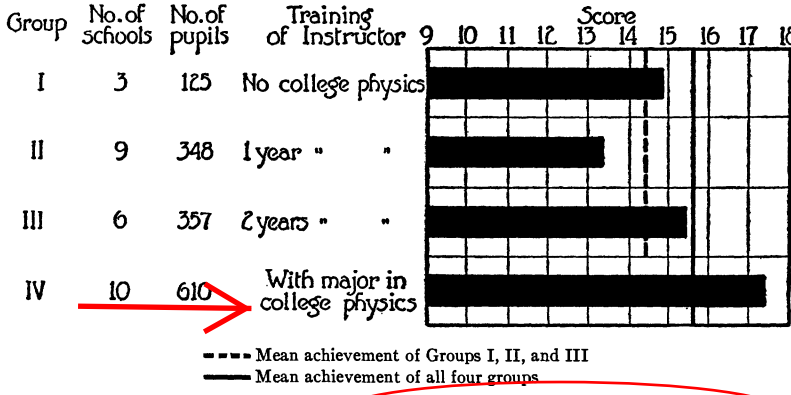

FIG. 9.—Comparison of mean achievements on tests in mechanics and heat of pupils taught by teachers with varying amounts of training.

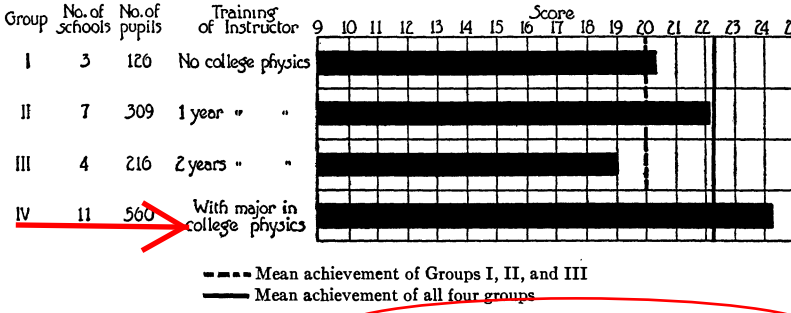

FIG. 10.—Comparison of mean achievements on tests in magnetism and electricity of pupils taught by teachers with varying amounts of training.

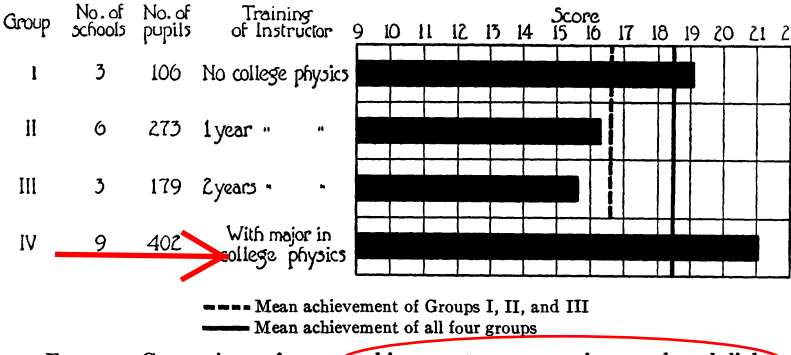

FIG. 11.—Comparison of mean achievements on tests in sound and light of pupils taught by teachers with varying amounts of training.

Do NSF-supported Teacher Preparation Programs Make a Difference?

- NSF contracted a study carried out in 1999 by TIMSS [Third International Mathematics and Science Study].
- The study assessed performance on the TIMSS physics test by students taught by teachers who had participated in NSF-sponsored teacher enhancement and physics material development programs.

Do NSF-supported Teacher Preparation Programs Make a Difference?

Results:

- Students taught by teachers in NSF-sponsored programs performed significantly better than a broad sample of all U.S. 12th-grade physics students.

- Performance was better in mechanics, electricity and magnetism, and modern physics.

Examples of NSF-Supported Programs

- University of Washington: Physics Education Group
- Arizona State University: Modeling Instruction
- Rutgers University: Intensive course sequence in physics-specific pedagogy
- University of Colorado: Learning Assistant Program
- San Diego State University: Constructing Physics Understanding

University of Washington Physics Education Group: *Physics by Inquiry*

- Pre-service teachers studied guided-inquiry instructional materials on light using research-based *Physics by Inquiry* program

- The pre-service teachers then taught these lessons in a 9^{th} grade classroom

- Their 9^{th}-grade students had much higher post-instruction scores on diagnostic tests covering the material (45%) than undergraduate university physics students taking the same tests (20%).

University of Washington Physics Education Group: *Physics by Inquiry*

Summer program at California State University San Marcos used *Physics by Inquiry* curriculum; they 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.

Arizona State University: Modeling Instruction for In-service Teachers

- Students of teachers who participate in “Modeling Workshops” consistently show better performance on the “Force Concept Inventory” [mechanics diagnostic test] than students of teachers who had not been through that or any comparable program. [Wells, Hestenes, and Swackhamer, 1995; Hake, 1998]
- 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 [Vesenka, 2005]

Rutgers University: Intensive Physics-Specific Teacher Education

RU program for pre-service education is based on a sequence of physics-specific pedagogy courses, founded on physics education research:

- Tests of program participants' physics knowledge (concepts and experimental process) show dramatically improved scores over the course of the program.
- Evaluations of participants by their mentor teachers and science supervisors yield very high ratings
- Students of program graduates show very high learning gains on mechanics diagnostic tests (normalized gains 0.4-0.6 on FCI]. [Etkina, 2010]

University of Colorado: Learning Assistant Pre-Service Program

- Undergraduate “Learning Assistants” show dramatic learning gains in both introductory and advanced-level physics courses. [Pollock, 2007]
- Former program participants implement science teaching practices that are more closely aligned with national science teaching standards than practices of comparable first-year teachers who had not been part of the program. [Gray, Webb, and Otero, 2010; 2011]
- CU’s dramatic increases (~400%) in number of certified physics teachers due in significant part to LA program [Otero, Pollock, and Finkelstein, 2010]

San Diego State University: Constructing Physics Understanding

The CPU project 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.

[Huffman, Goldberg, and Michlin, 2003; Huffman, 2006]

Summary

- The number, diversity, and consistency of outcomes provide evidence for effectiveness of research-based physics teacher education methods.
- These outcomes are consistent with 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.
- Weight of evidence indicates 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.