The Conflict Between Recommendations and Reality: A Short History of U.S. Physics Teacher Education from 1880-2014

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Acknowledgments

- Valerie Otero has contributed to the research and analysis presented in this talk.
- Support from PhysTEC has played an important role in furthering this work over the past six years.

Outline

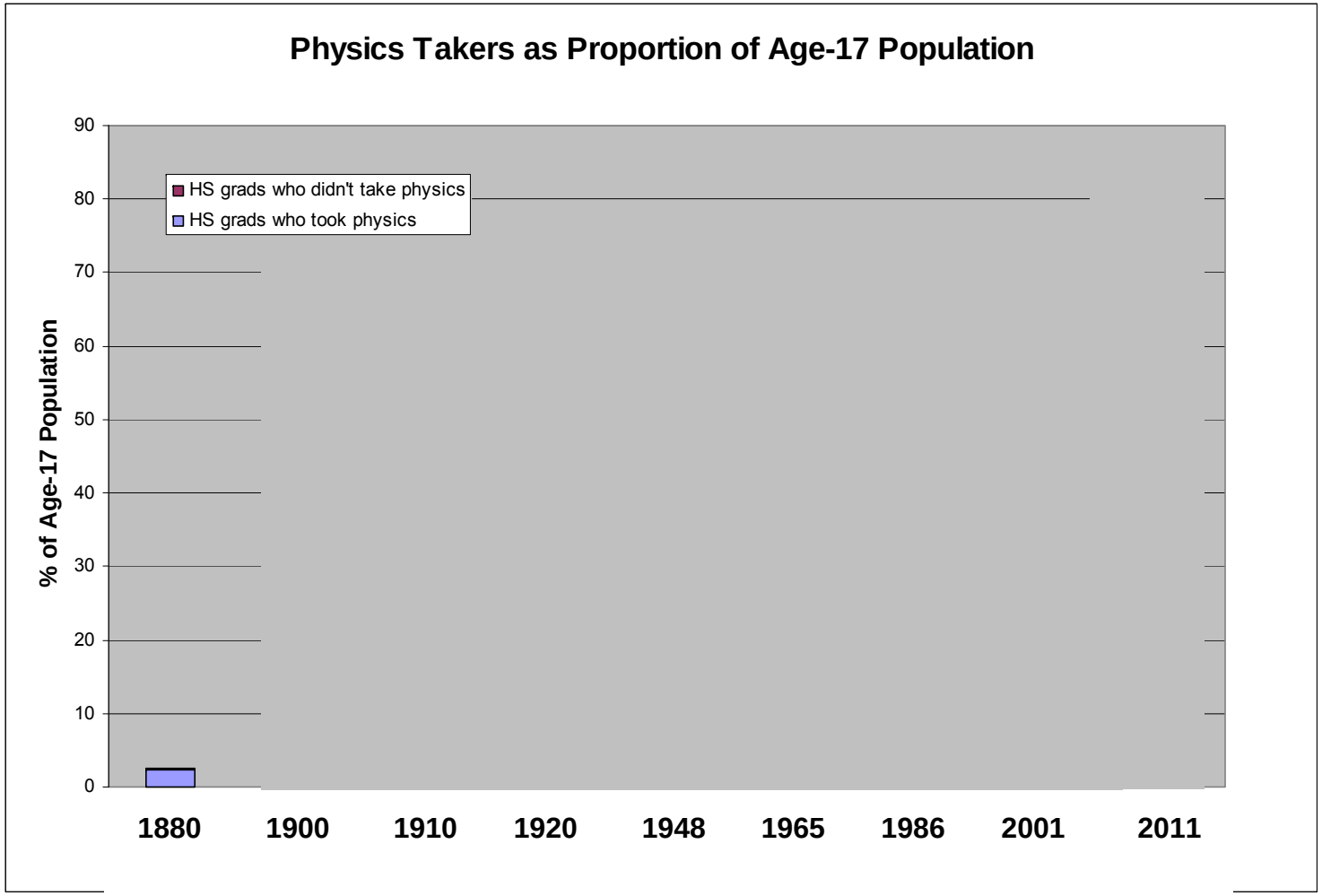
- **Historical context:** The development of high school physics in the U.S.
- **Recommendations:** Guidelines for teacher education by U.S. physics community
- **Reality:** How U.S. physics teachers have actually been prepared—and why

Outline

- **Historical context:** The development of high school physics in the U.S.

Early Days (Before 1910)

- Fewer than 10% of all high-school-age students actually graduated from high school
  - *However:* explosive growth in enrollments began in the 1880s and continued for the next 50 years
- Physics was often required for college admission
  - but requirements were loosened ~ 1900
- Nearly all high school graduates took physics
  - but fewer than one-third graduated
- Most (> 90%) high schools were very small and did not have specialist physics teachers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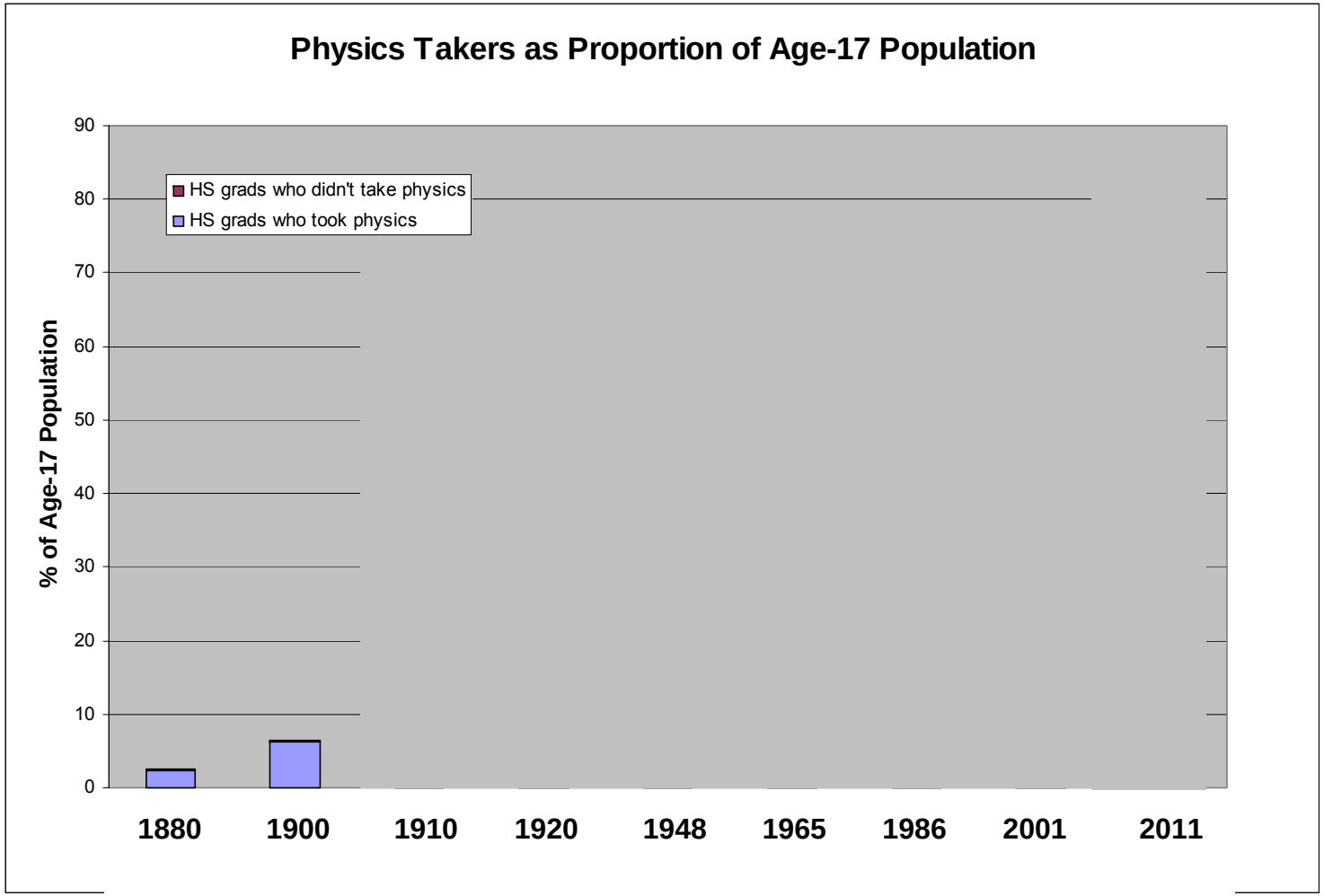
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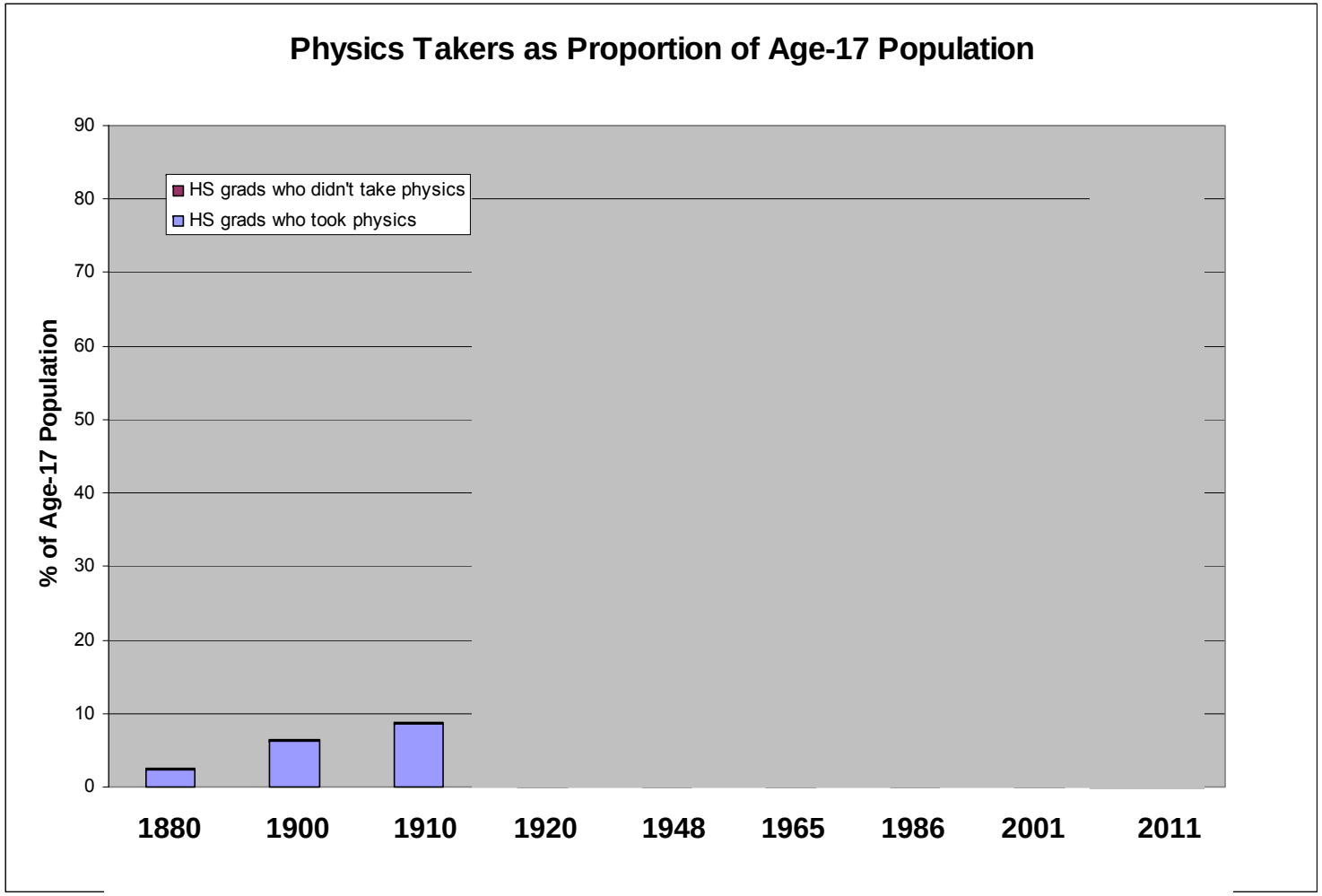
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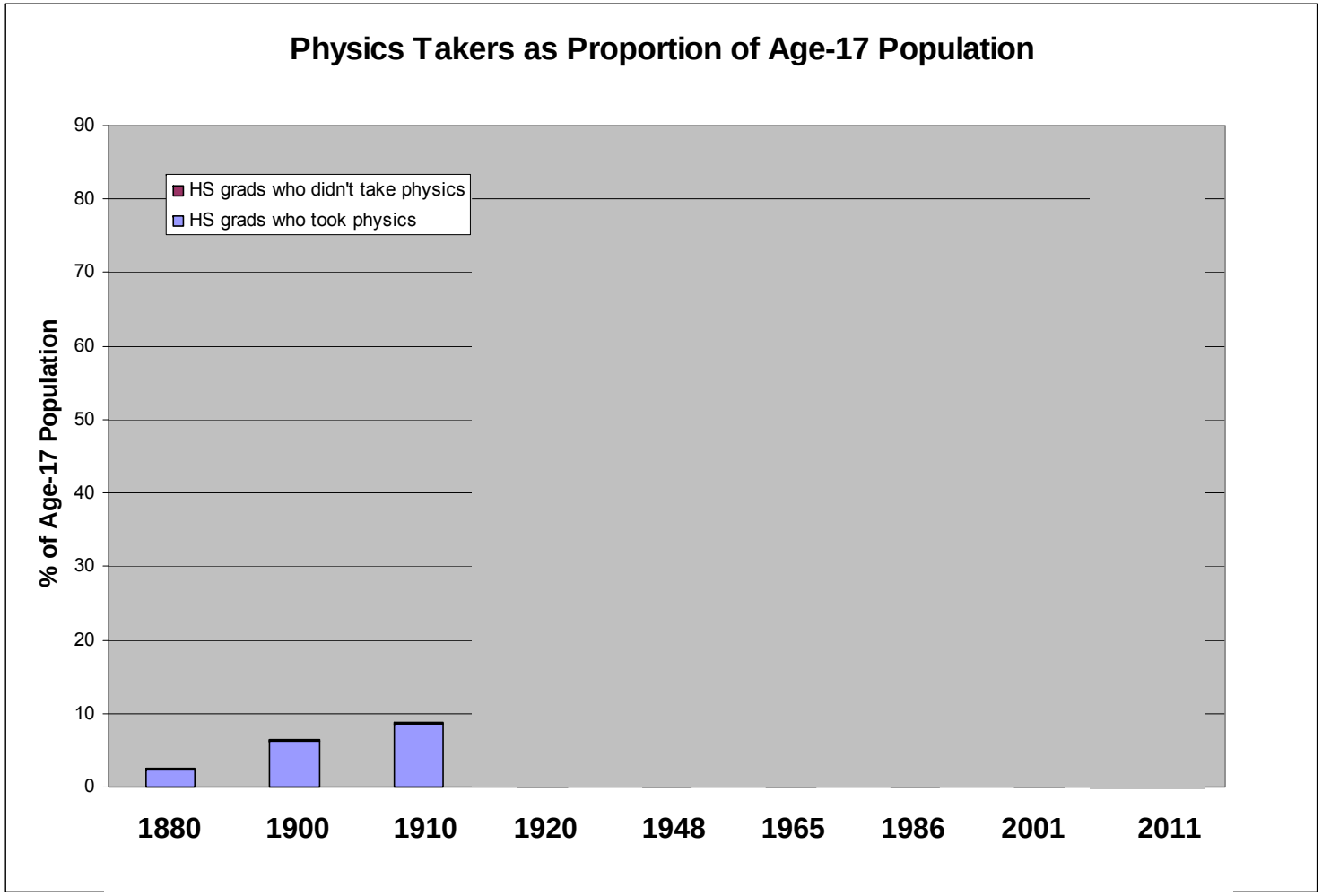
Development of “Education for the Masses” (≈1900-1950)

- 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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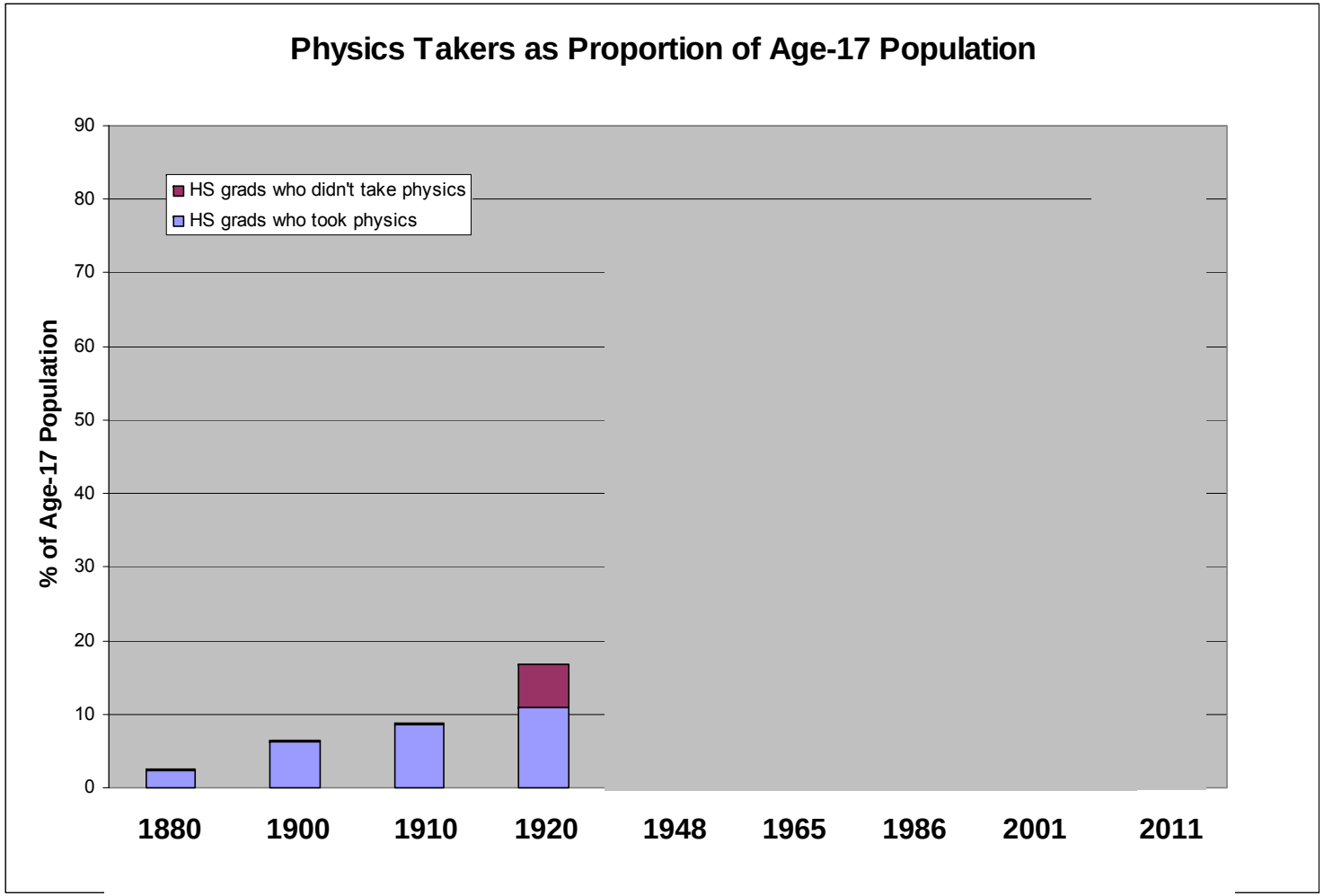
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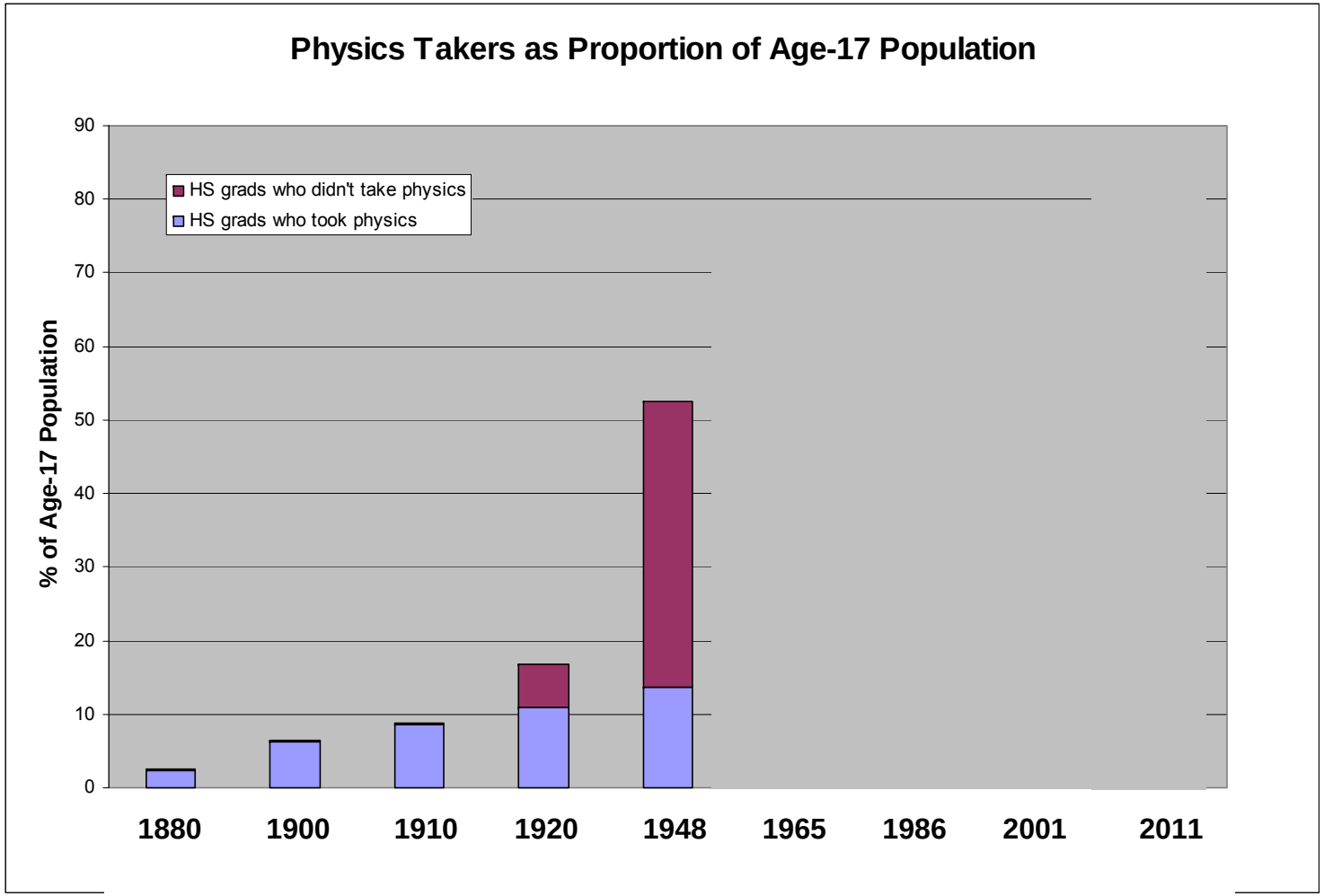
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Primary Constraints

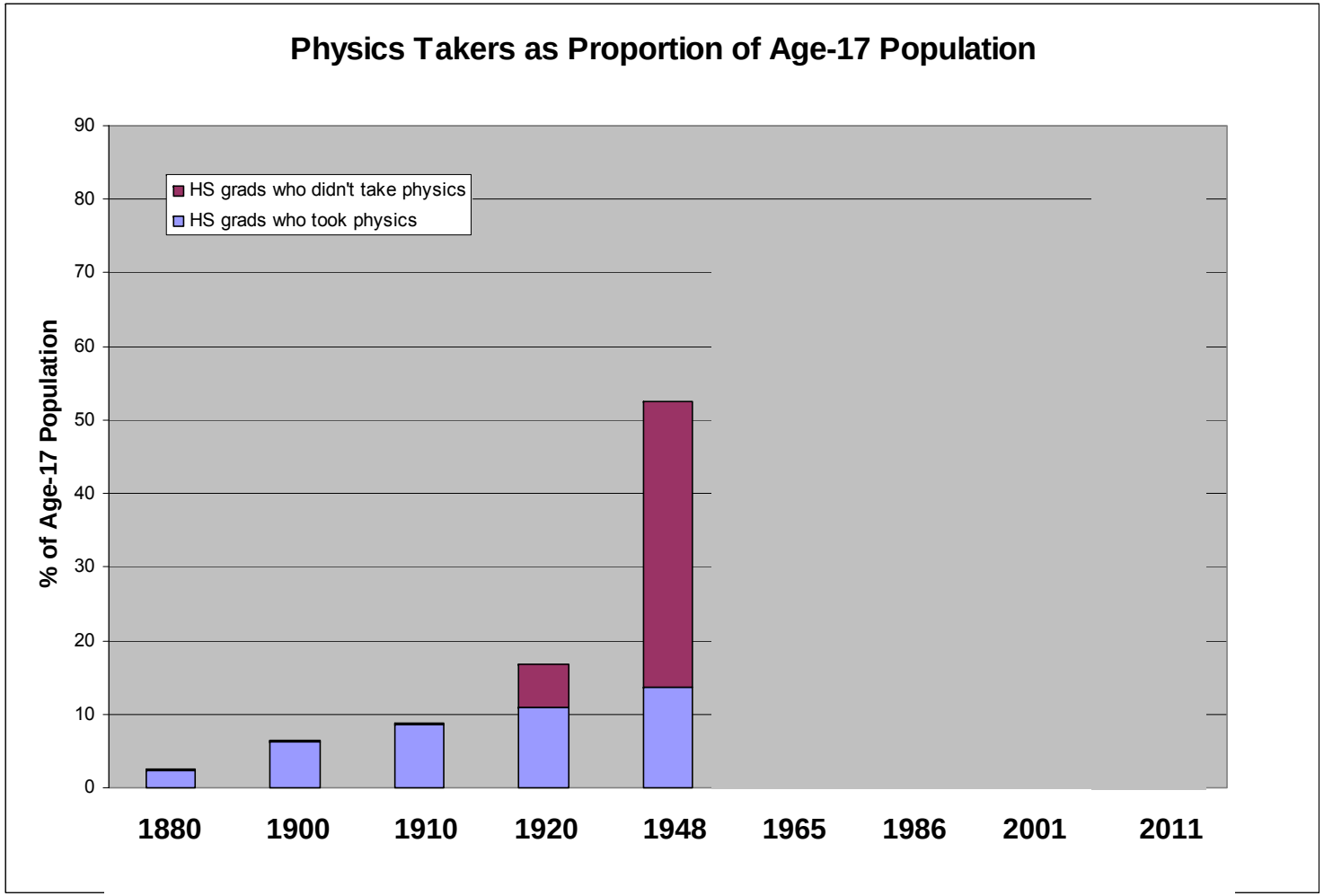
- Persistent large proportion of very small schools
- Physics taught only as one-year course, for third- or fourth-year students (no gradual “easing in” to college-prep physics courses in early grades)
- College and high school requirements for physics were (mostly) eliminated around 1900

Primary Outcomes

- Most physics teachers taught multiple subjects, had primary background in subjects other than physics.
- There was *never* any steady supply or systematic production of well-prepared teachers
- Educational system at all levels K-20 developed high tolerance for low effectiveness of high school physics teaching (e.g., college courses assuming little or no high school preparation).

Reform Period (~1956-1979)

- Catalyzed by Sputnik (1957), a *dramatically* increased emphasis on physics (and all math/science) education
- Development of federally funded "reform" curricula for high school physics teaching
  - Physical Science Study Committee *(PSSC)*
  - Project Physics
- Massive federally funded effort to implement in-service physics teacher education ("summer institutes")
- Graduation-rates increased, but physics enrollments stagnated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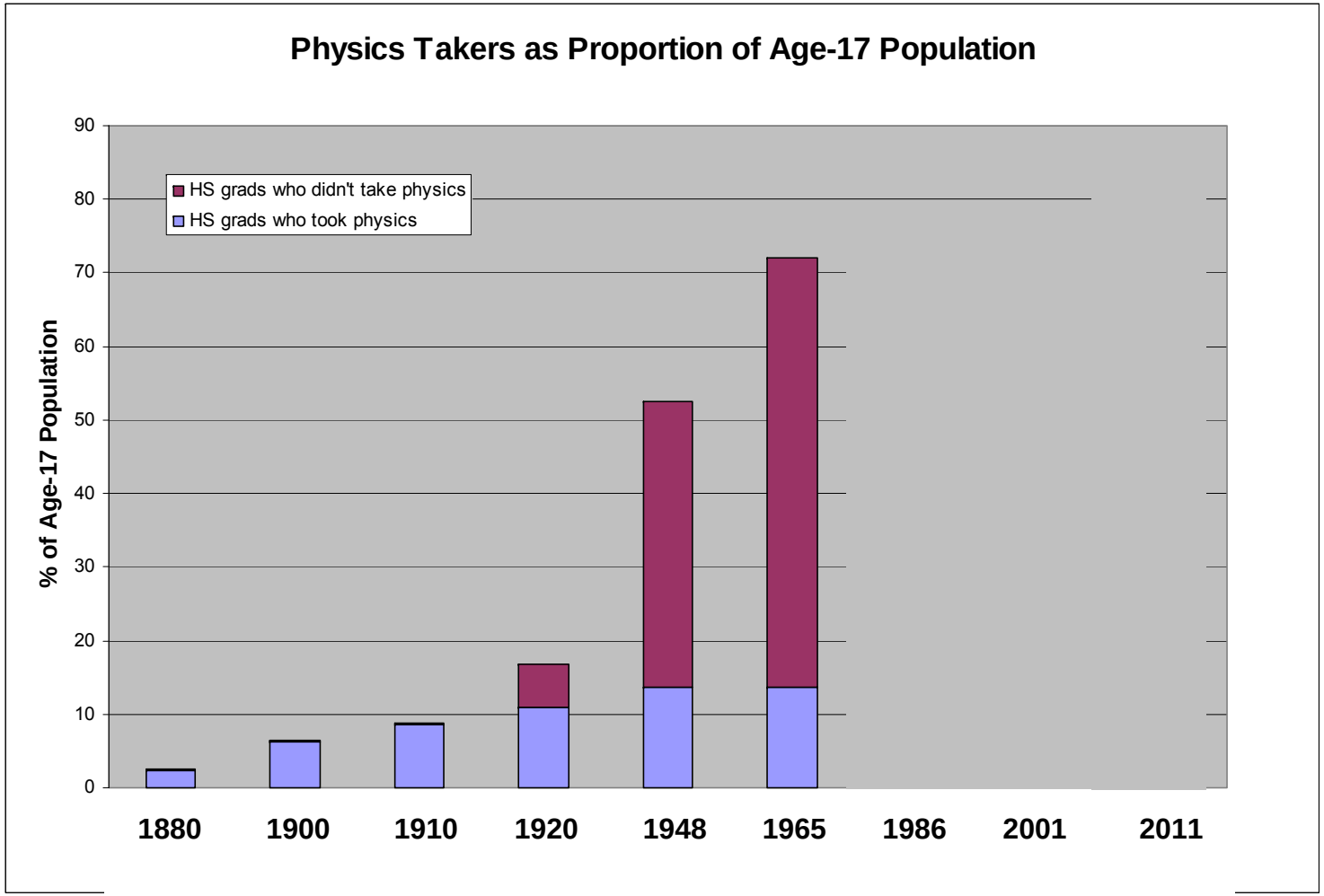
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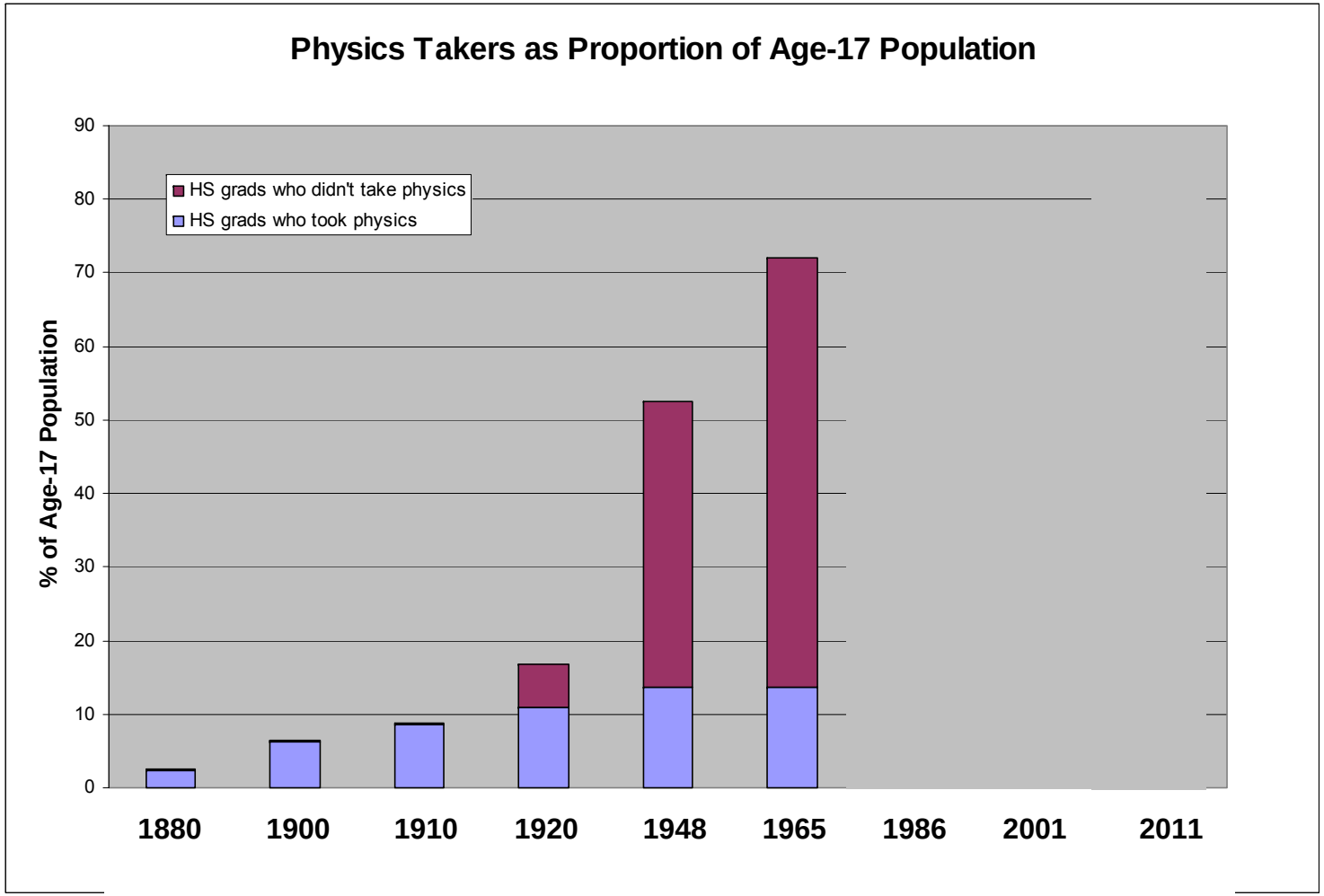
Consequences

- 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.

Recent Period (~1980-2014)

- Dramatic rise in physics enrollments, led by “conceptual” physics and Advanced Placement
- High school textbooks and physics teacher education influenced by development of physics education research at the college level
- Unprecedented levels of physics teacher education *still* fall far short of recommendations laid out 50 years ago and earlier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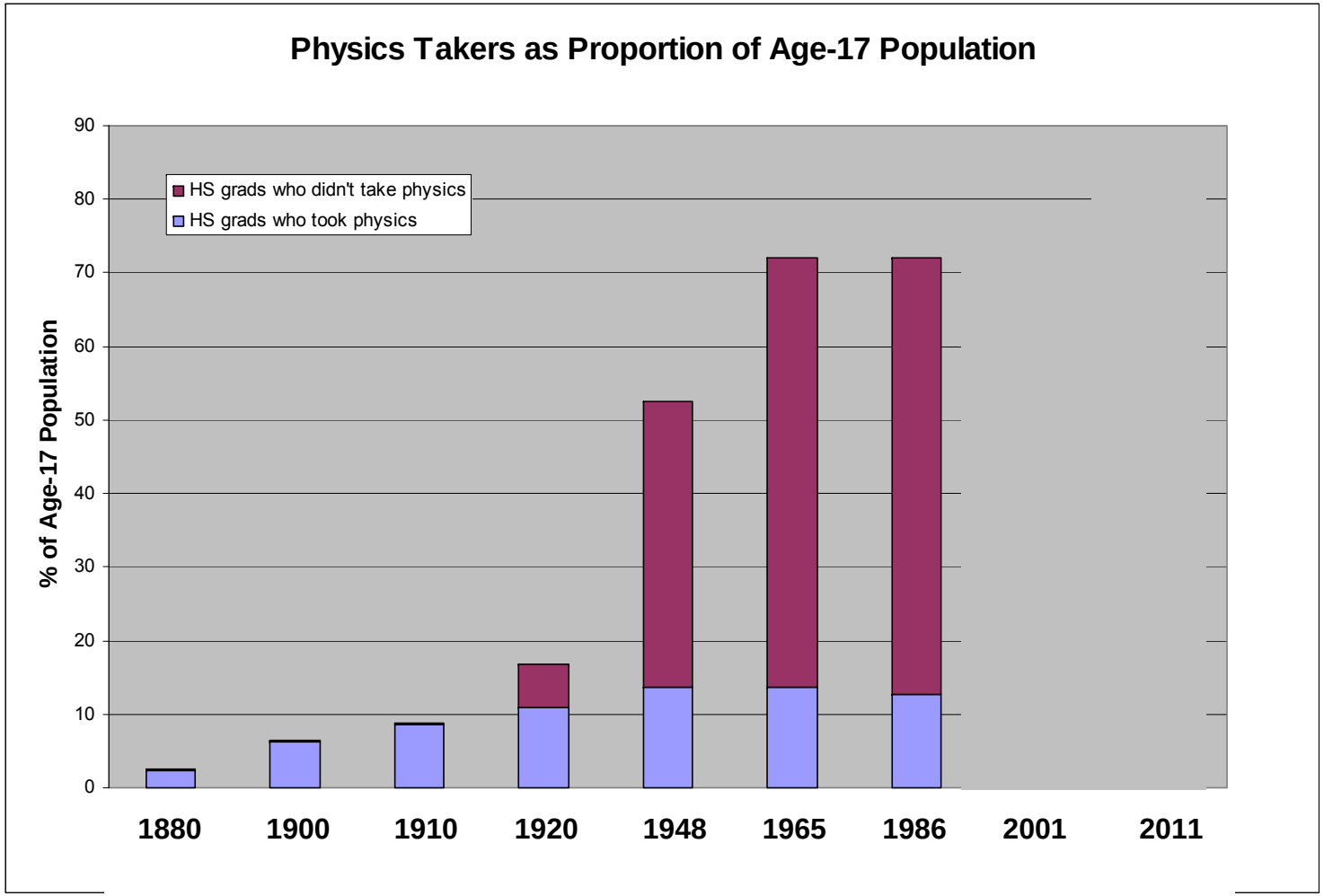
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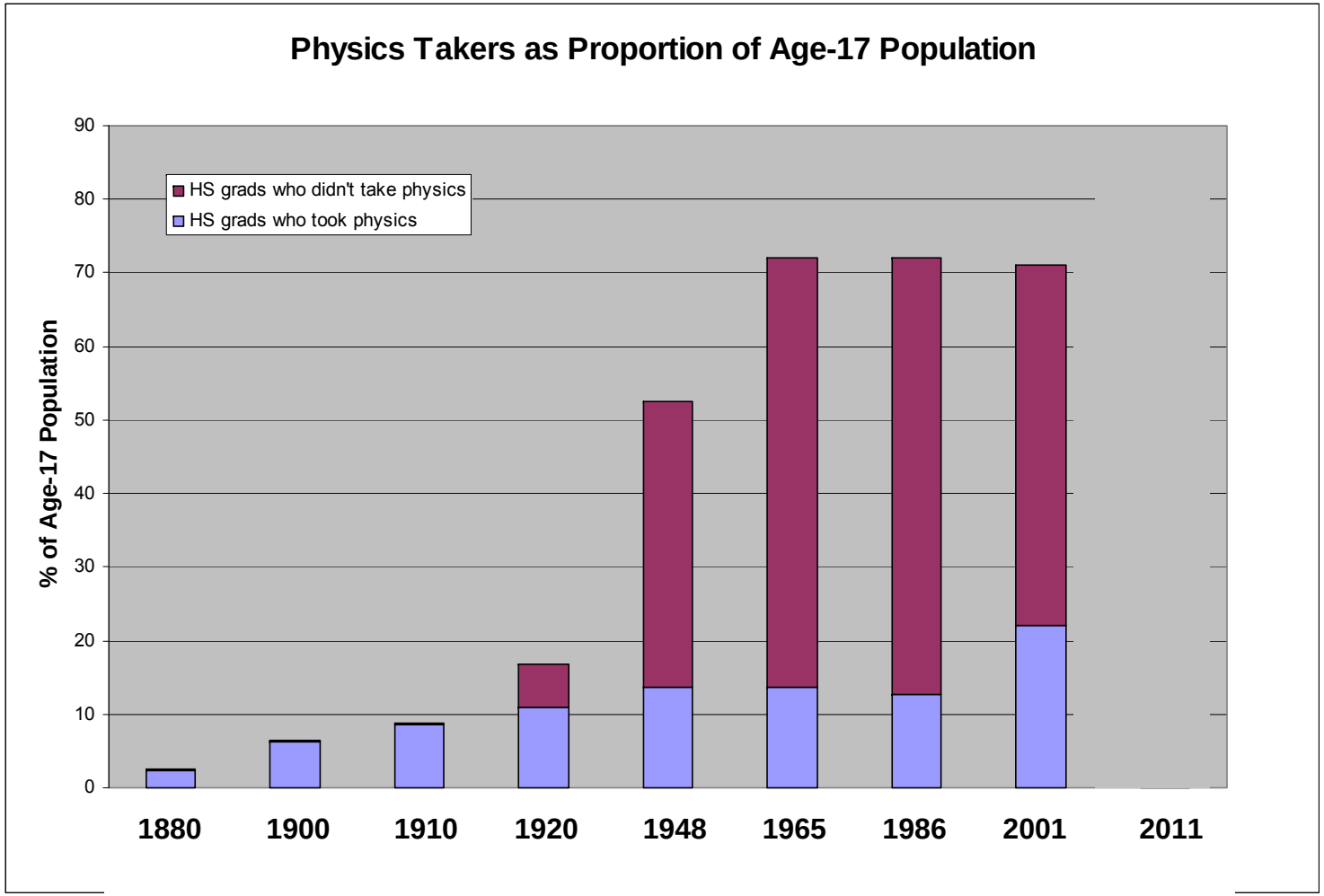
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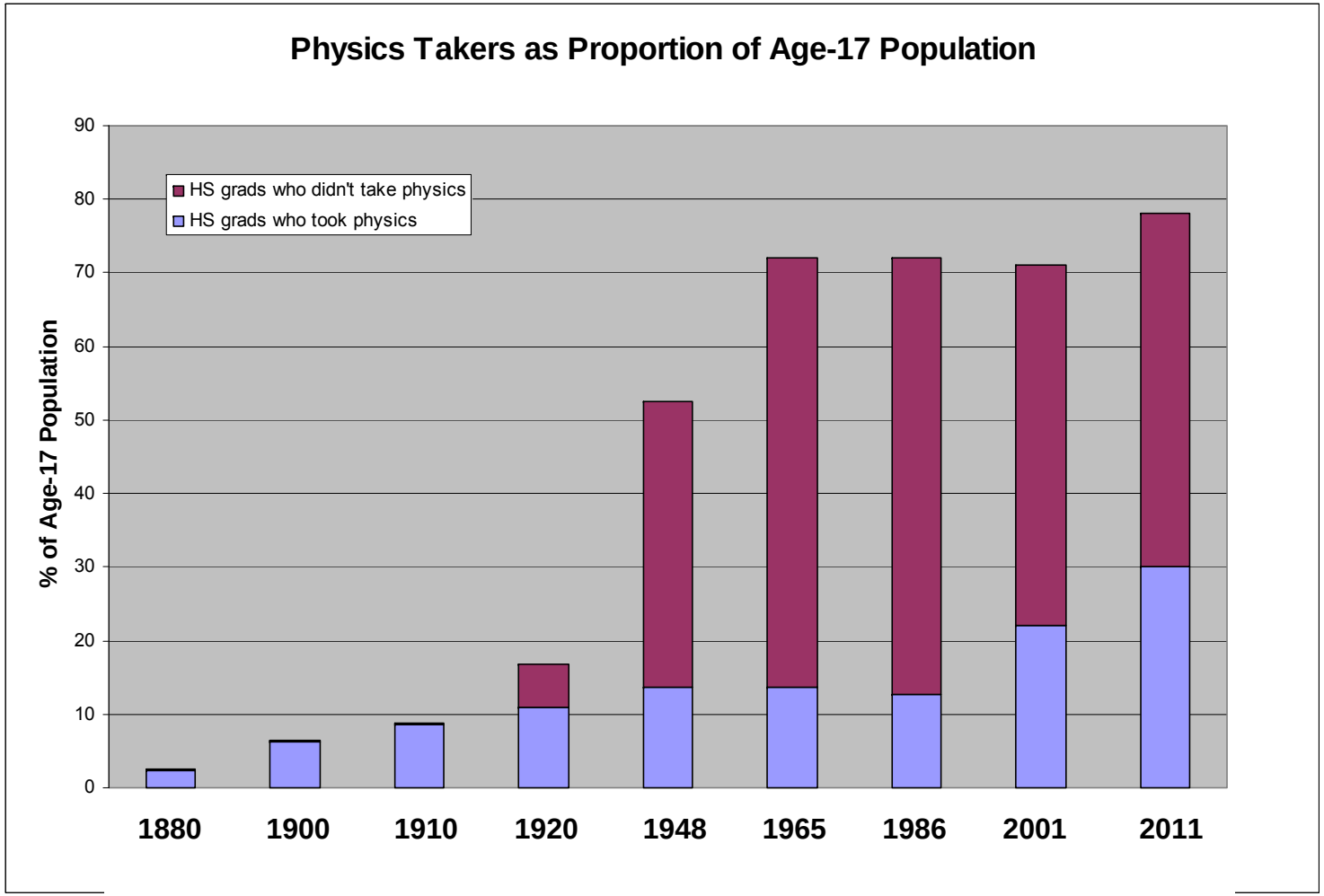
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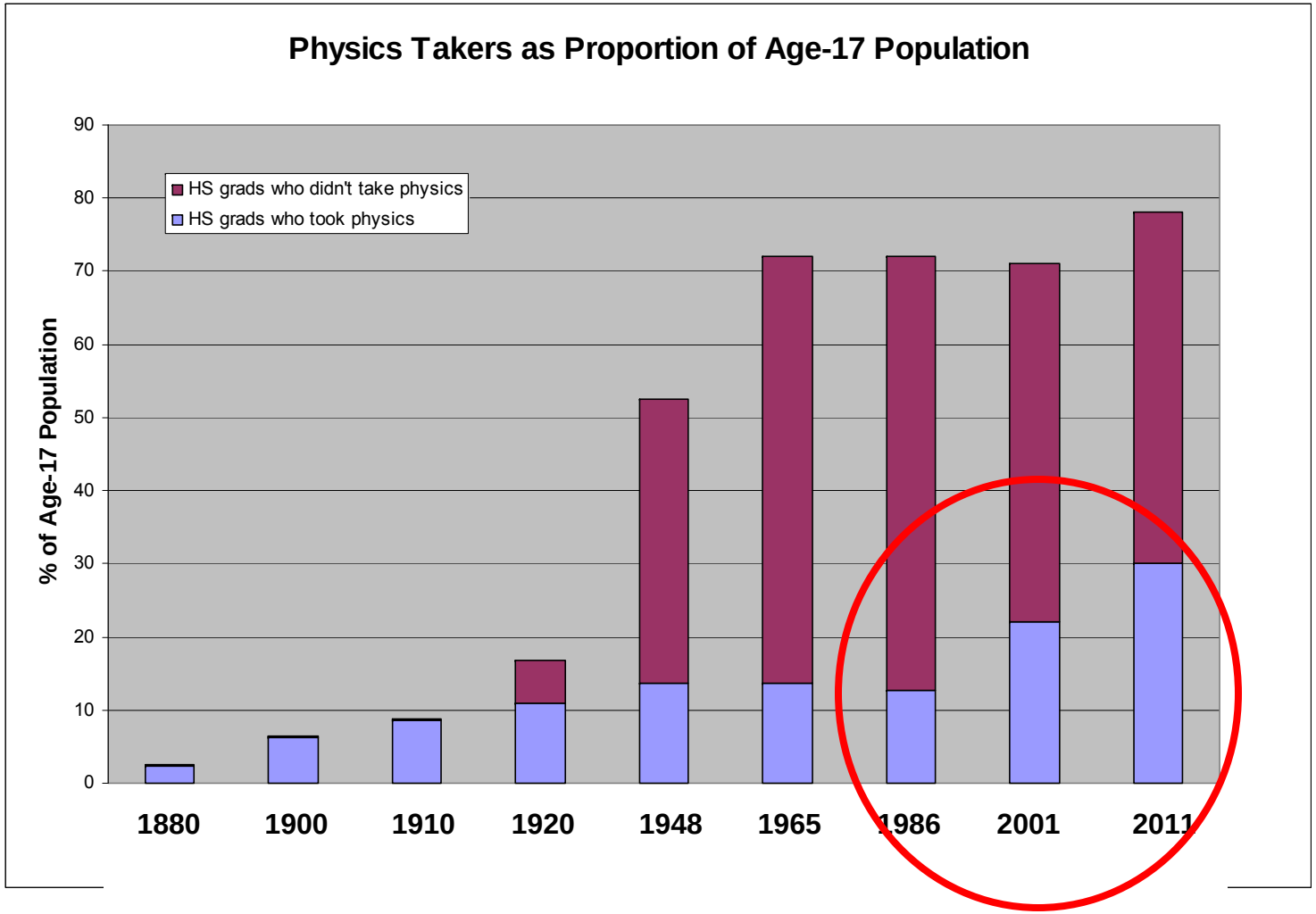
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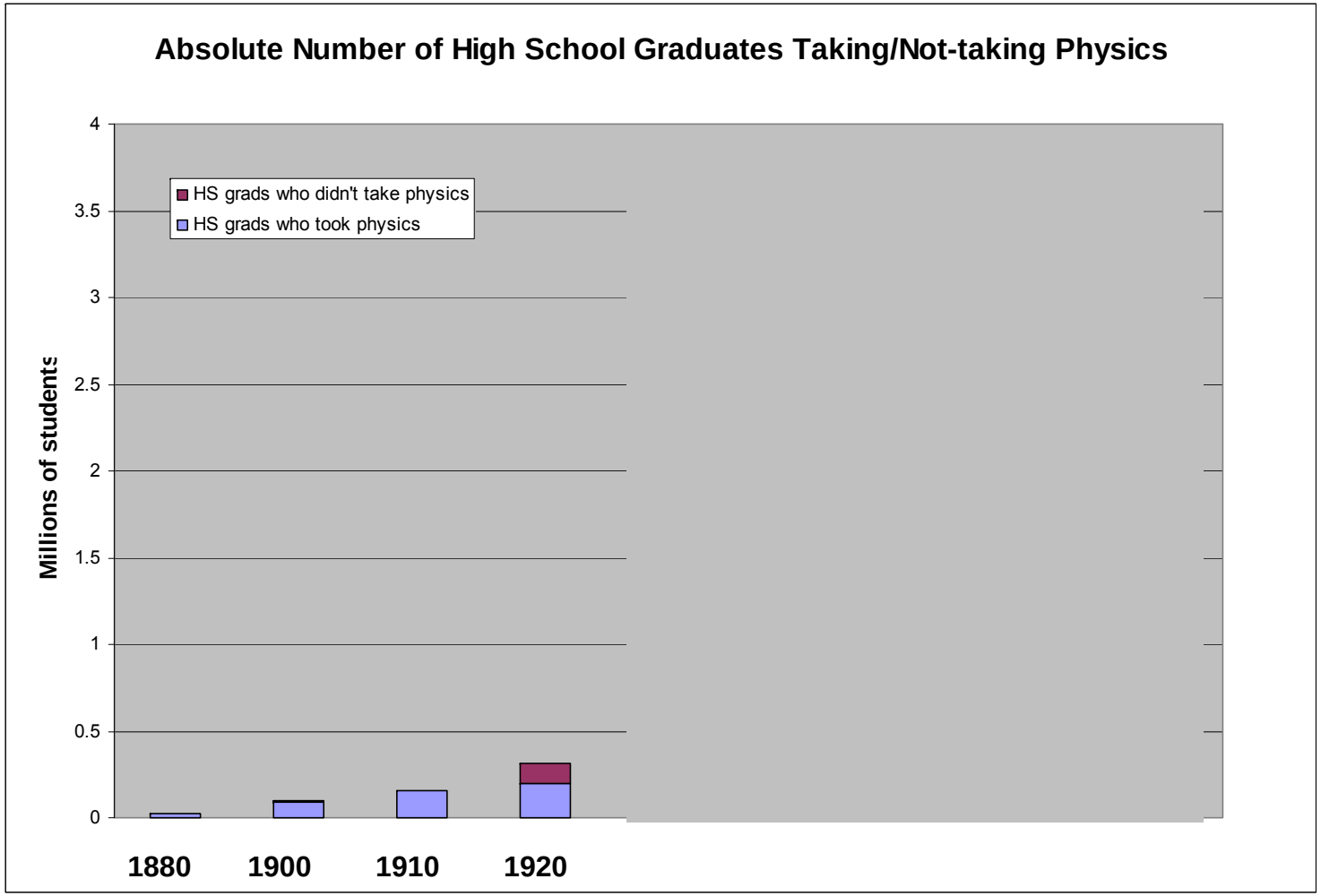
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Millions of students
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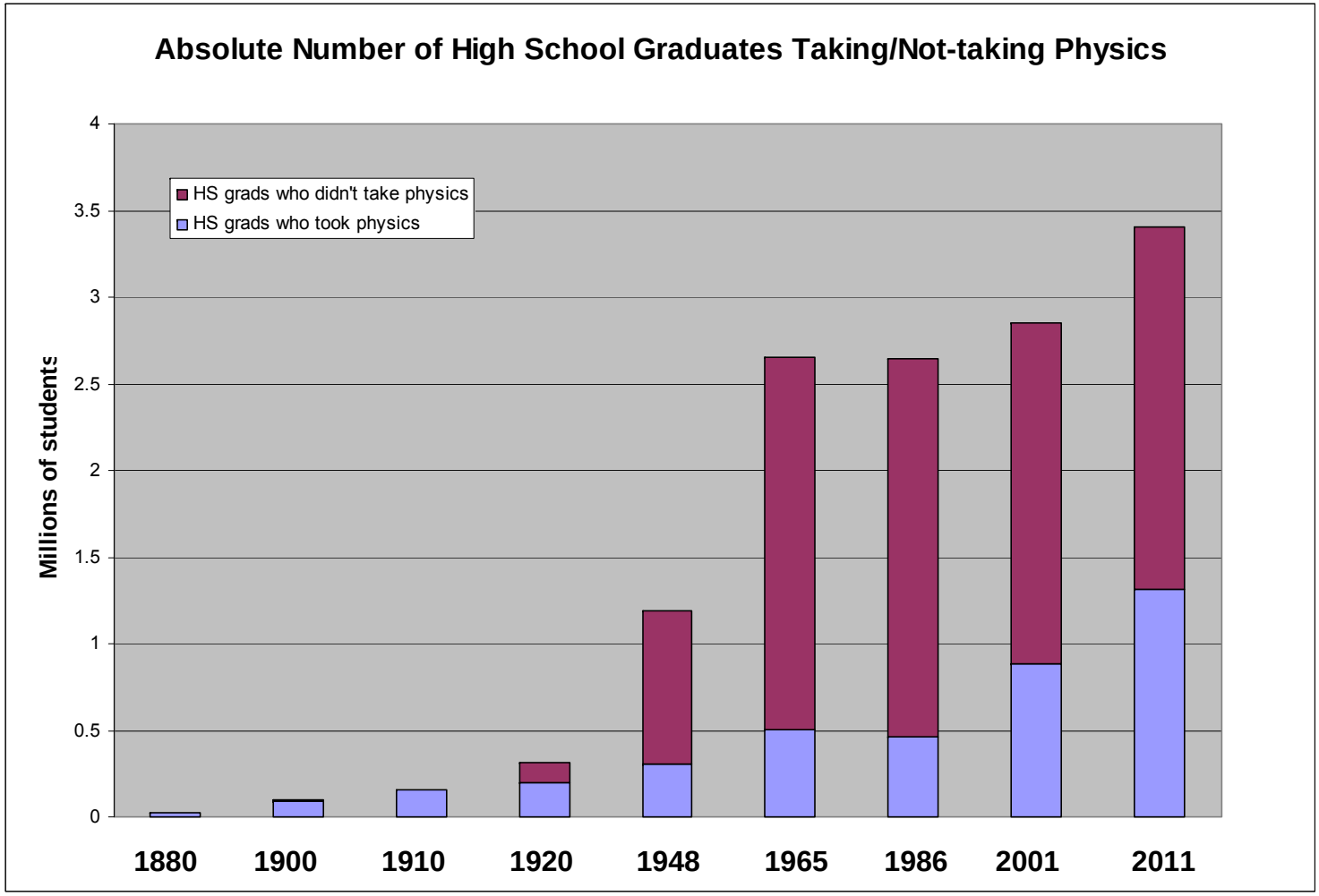
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- **Recommendations:** Guidelines for teacher education by U.S. physics community

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

Common Themes I:
Deep Content Knowledge is Necessary

- **1884:** "…the teacher should have a knowledge far exceeding the amount he must teach…." [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
- **1968:** AAPT/AIP recommend minimum of 24 hours, or 18 hours plus "in-service training"

1884 Report on Teaching of Physics:

Questionnaires sent to dozens of high schools, colleges, and “normal” [teacher-training] schools

“Many of the replies [from schools] 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;

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

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)]

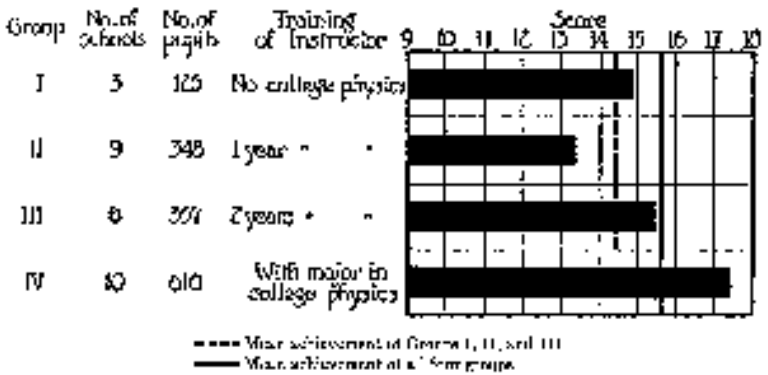


FIG. 9.—Comparison of mean achievements on tests in mechanics and heat of pupils taught by teachers with varying amounts of training.

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

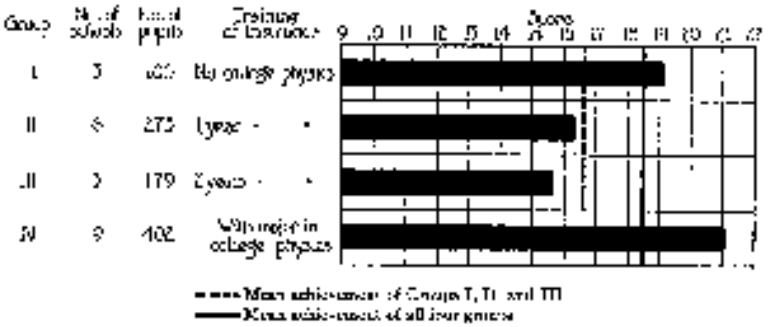
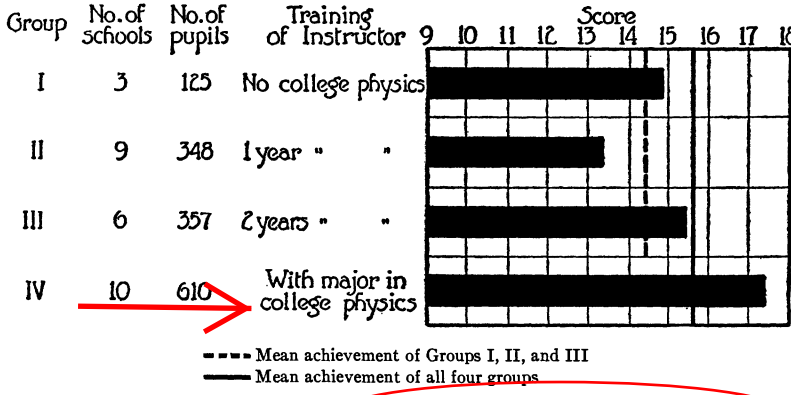


FIG. 11.—Comparison of mean achievements on tests in sound and light of pupils taught by teachers with varying amounts of training.



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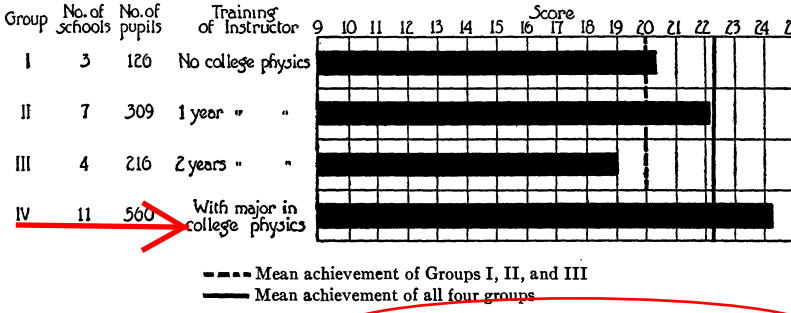

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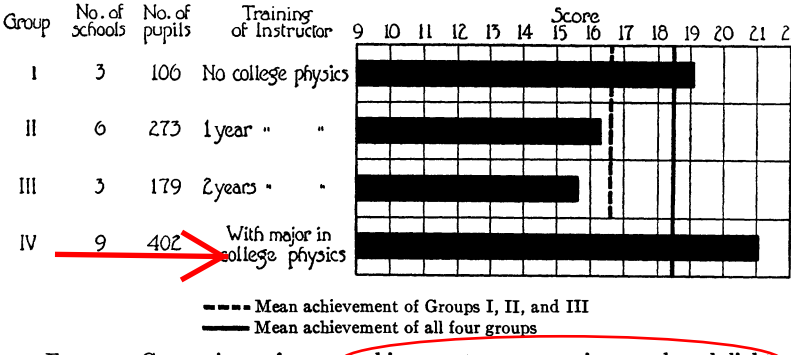

FIG. 11.—Comparison of mean achievements on tests in sound and light of pupils taught by teachers with varying amounts of training.

Common Themes II:
Prepare Teachers to Teach Through Inquiry

- **1884:** 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." [Wead, pp. 117-122]

- **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."

“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.

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

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

- **1968:** AAPT/AIP committee advocates courses for teachers 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 (NAS) 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."

Common Themes III:
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:** AAPT/AIP committee 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."

Other Recommendations:

- **1946:** "…joint participation in the supervision of practice teaching by subject matter departments and the department of education can work to the great advantage of the teachers-in-preparation." *[AAPT, Committee on the Teaching of Physics in Secondary Schools]*
- **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…" *[AAAS and AACTE, Joint Commission on the Education of Teachers of Mathematics and Science]*
- **1972:** "…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." *[AAPT and AIP, Commission on College Physics]*
- **1973:** "…institutions that prepare teachers [should] be responsible for offering in-service workshops, seminars, and intensive summer programs [for practicing teachers]." *[National Academy of Sciences, Physics Survey Committee]*

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- **Reality:** How U.S. physics teachers have actually been prepared—and why

Key Historical Events: II

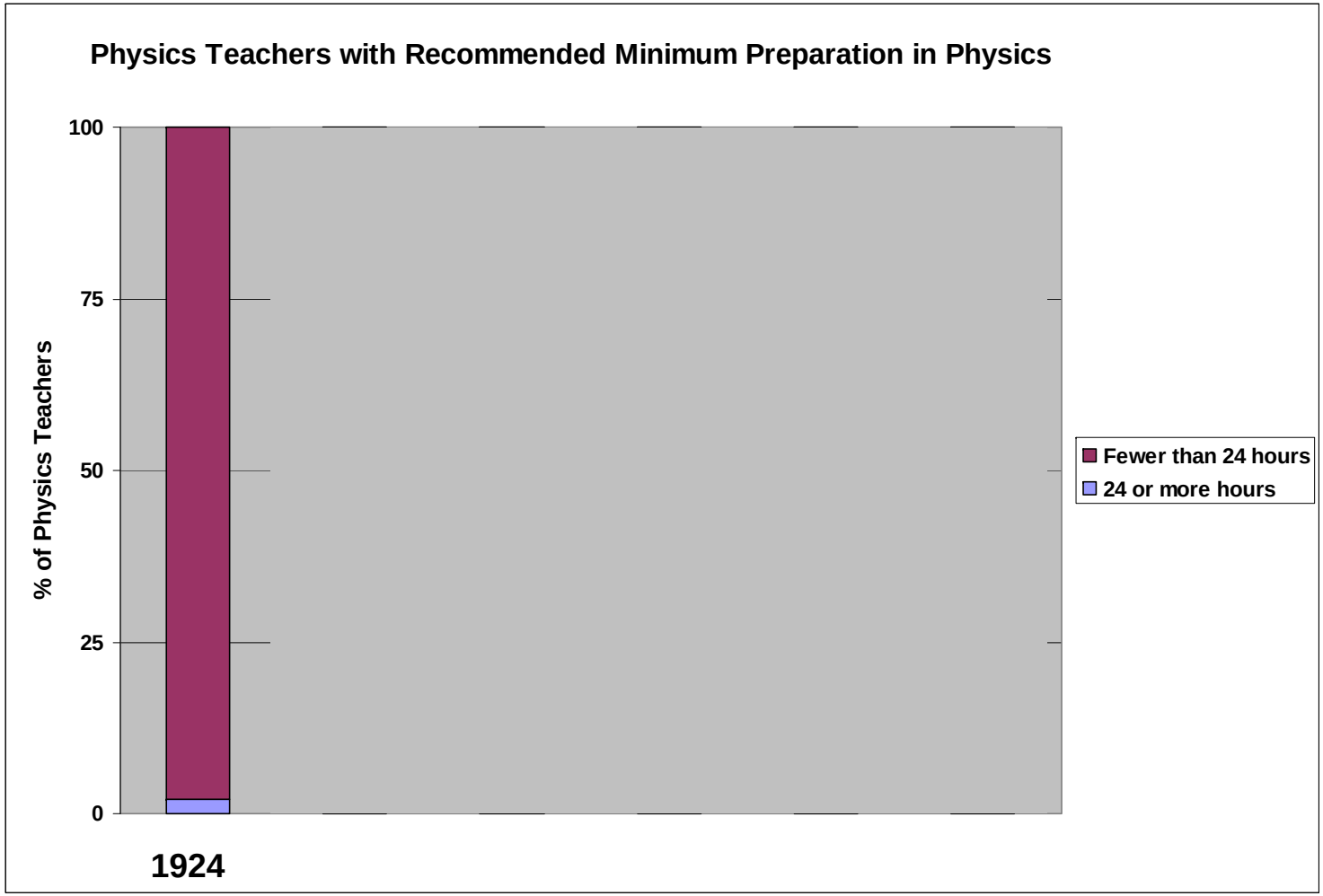
- **1939:** AAPT forms “Committee on the Teaching of Physics in Secondary Schools.”
- **1946:** AAPT reports on “deficiency in the number of well-trained science teachers.”
- **1947:** First summer institute for in-service physics teachers, sponsored by GE, to remedy deficient preparation.
- **1955:** First NSF-sponsored summer in-service institutes for physics and chemistry teachers
- **1966:** National Academy of Sciences cites “severe educational crisis for physics” in the high schools, links it to shortage of competent high school physics teachers.

Key Historical Events: III

- **1968:** Following extensive investigation, Commission on College Physics (AAPT/AIP) issues report “Preparing High School Physics Teachers”
- **1973:** National Academy of Sciences issues new report, states that institutions should take active role in in-service physics education.
- **2012:** Following four-year investigation, release of report by Task Force on Teacher Education in Physics (T-TEP) [APS/AAPT/AIP].
  - Findings and recommendations consistent with those made in previous reports

Most Physics Teachers Have Less Than Recommended Preparation

- Most U.S. physics teachers have now—and have always had—less than the recommended physics preparation, equivalent to a major or minor in physics (~24 semester hours)
- Average preparation has increased substantially over the years, but more than 50% of teachers still fall short



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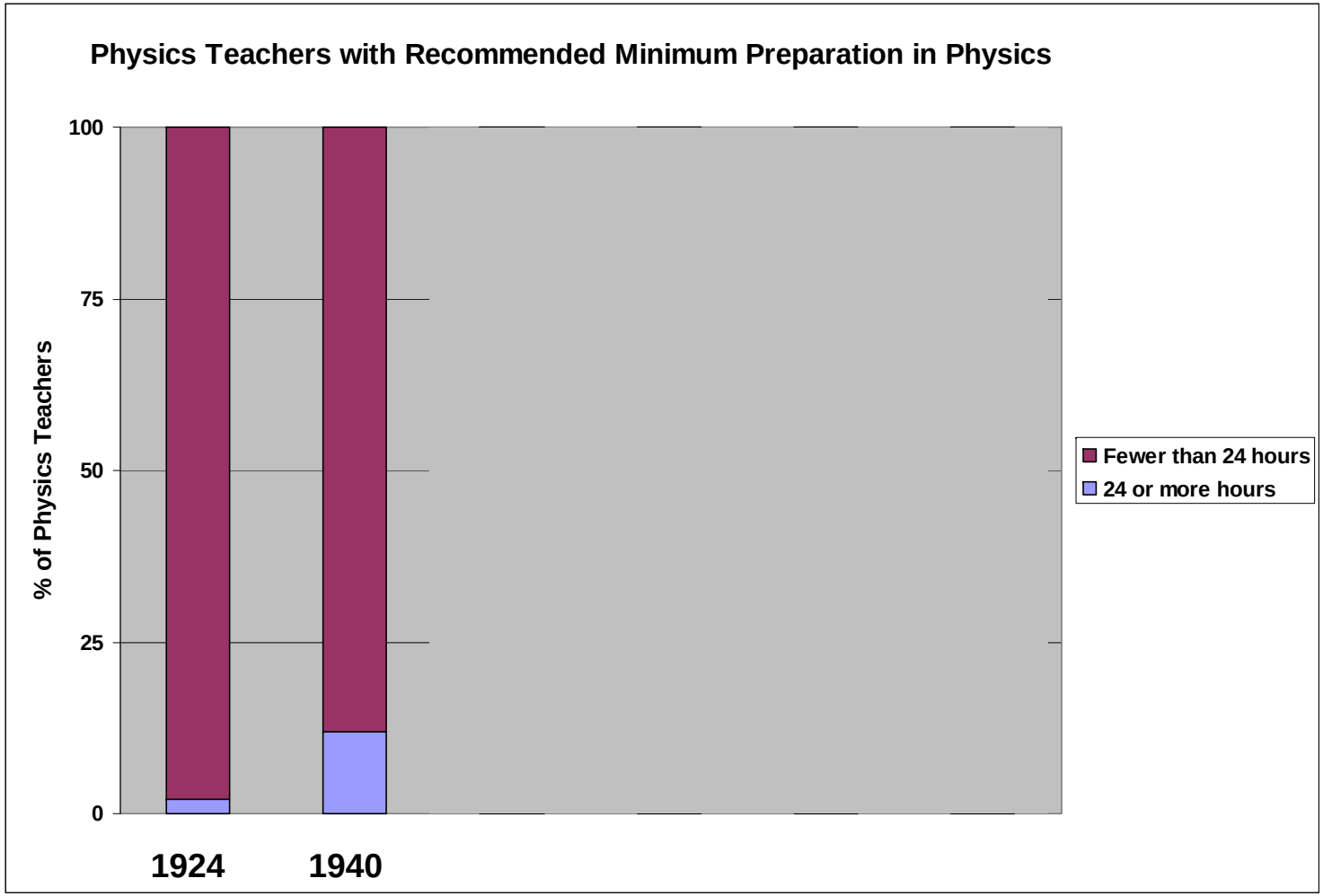

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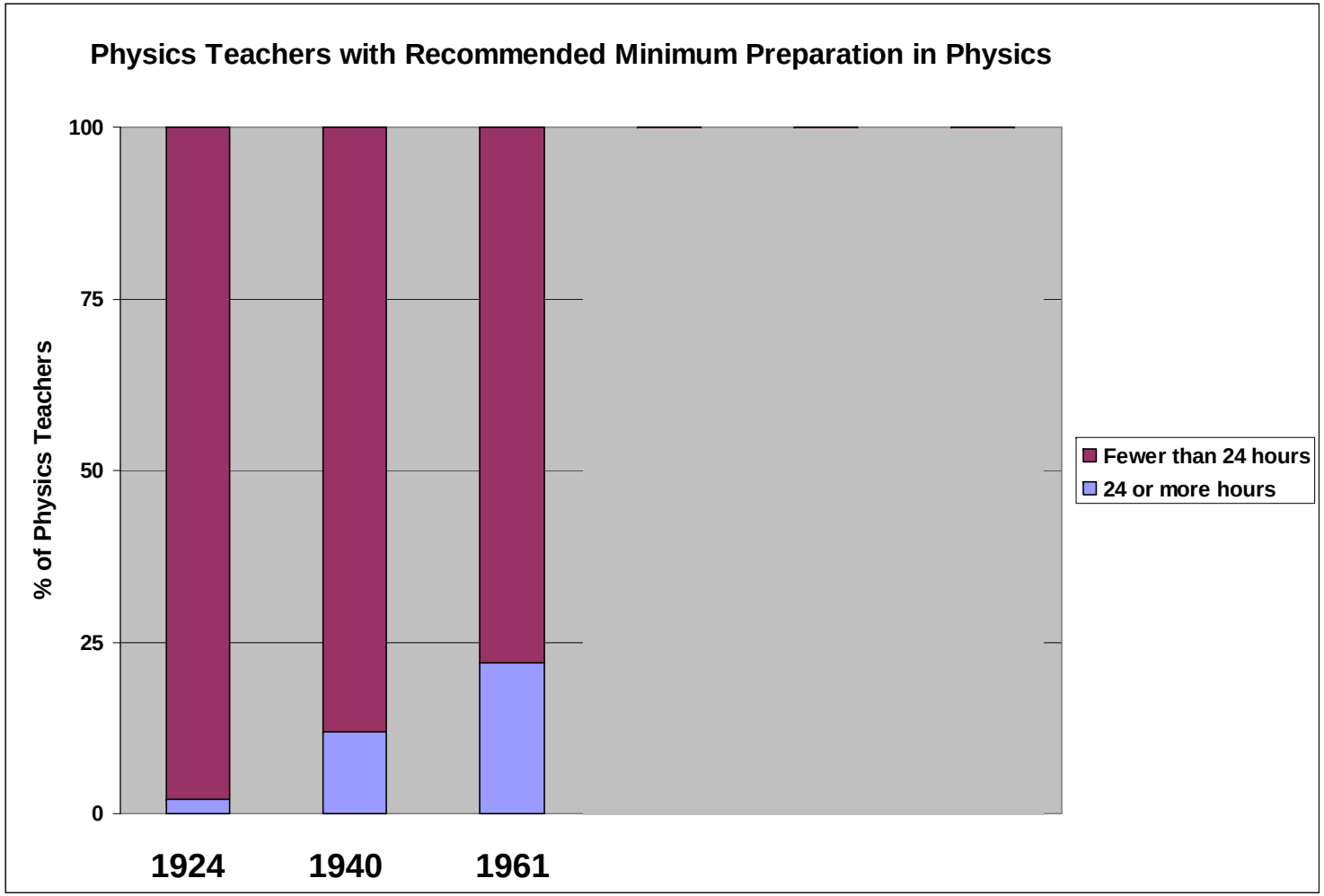

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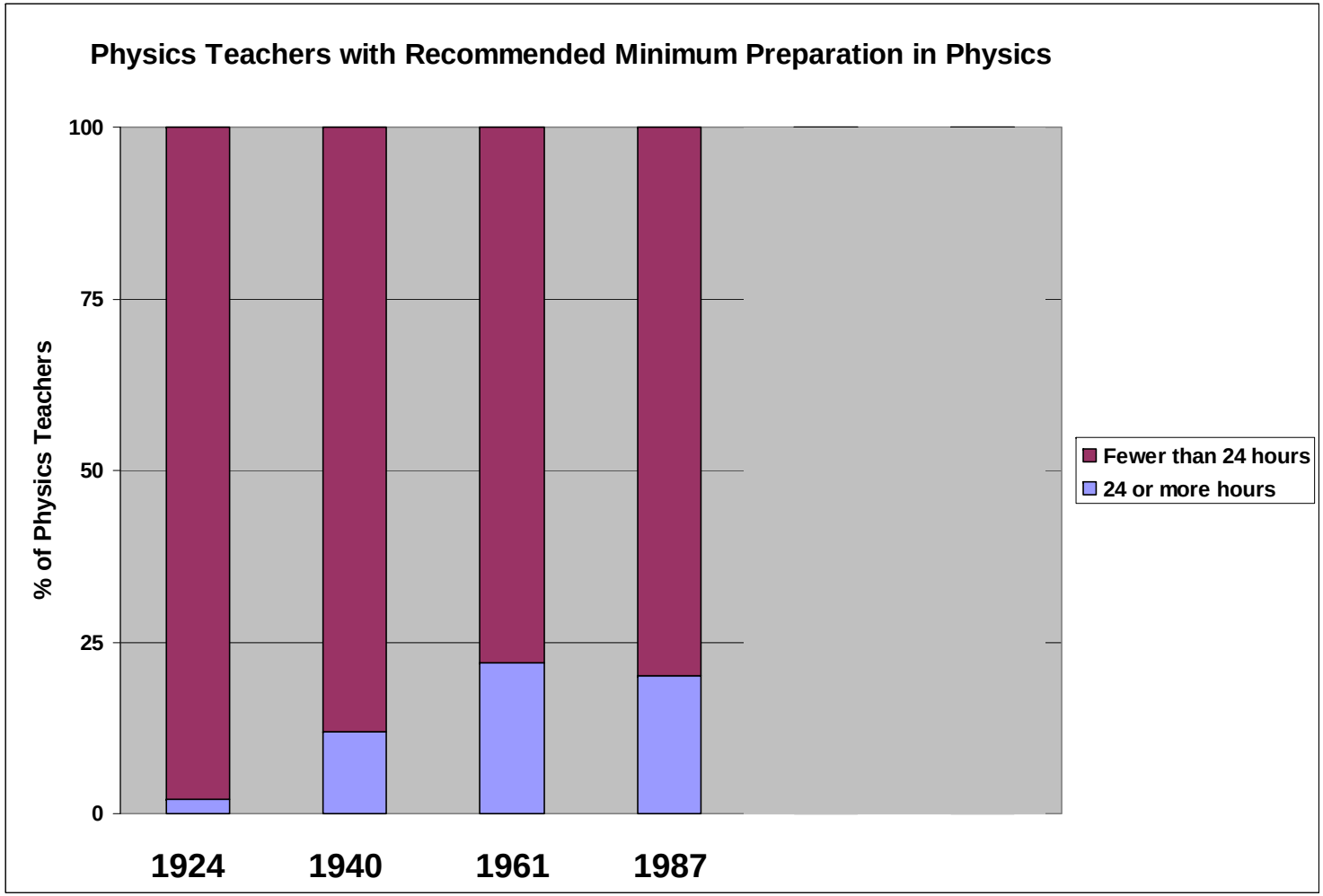

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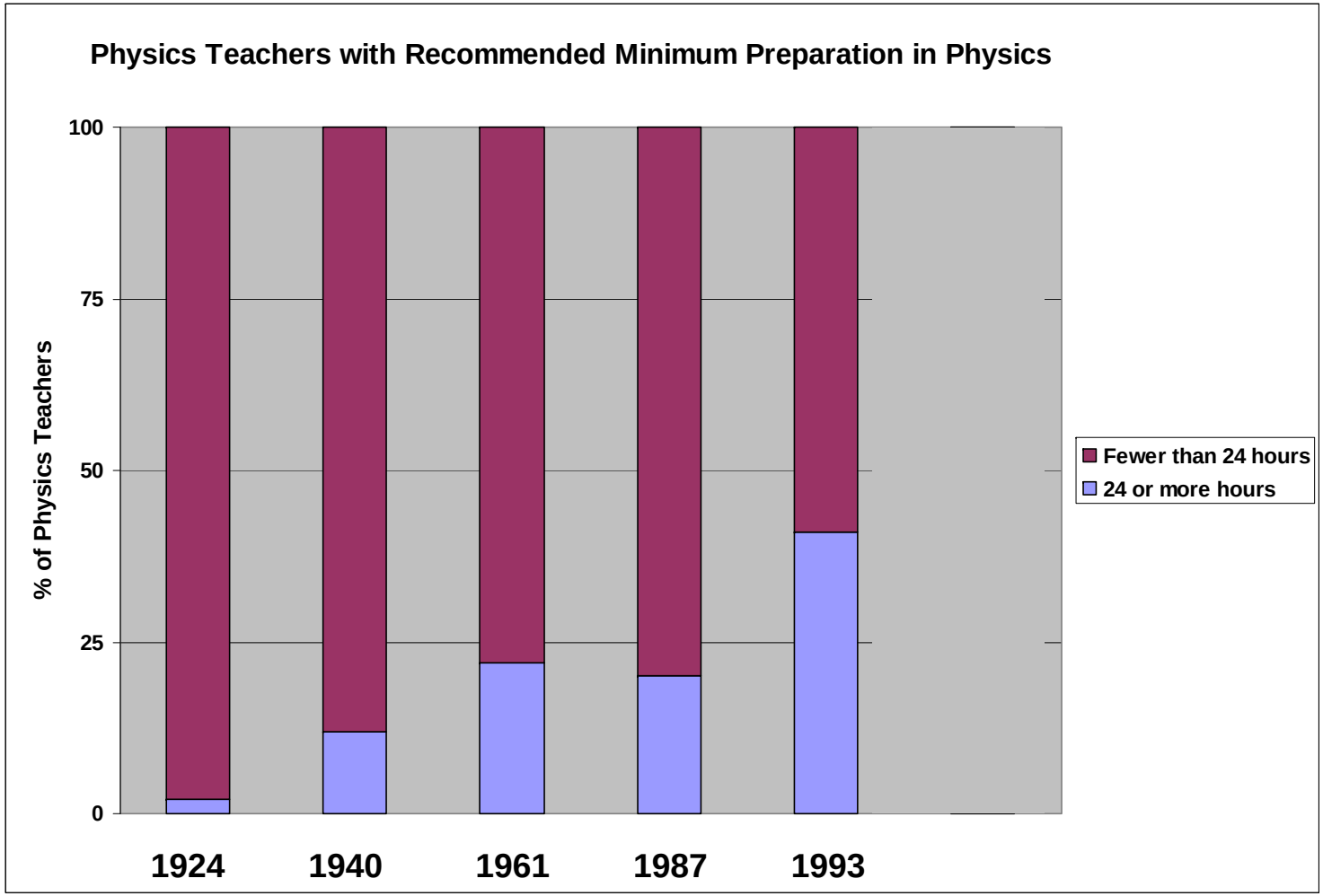

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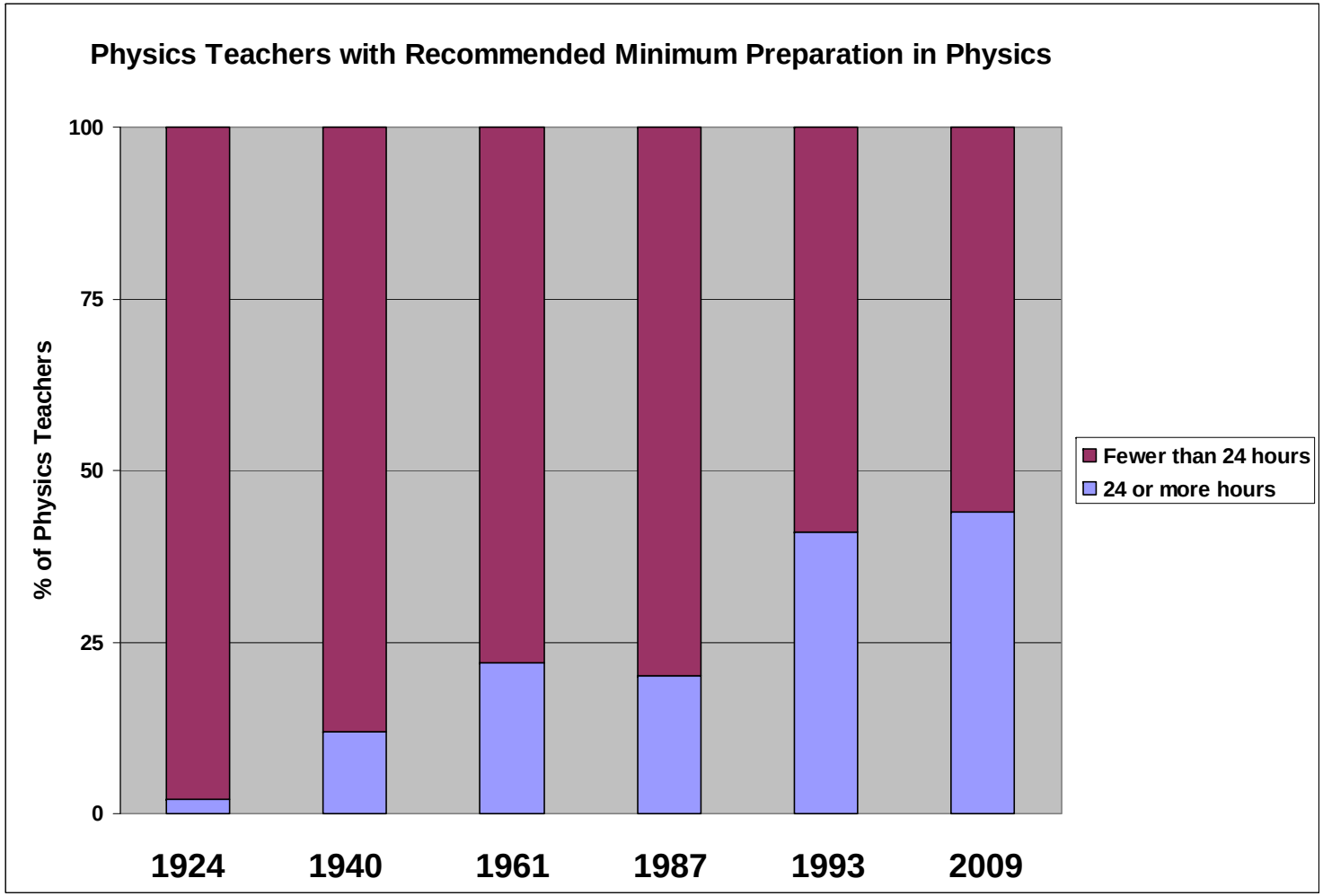
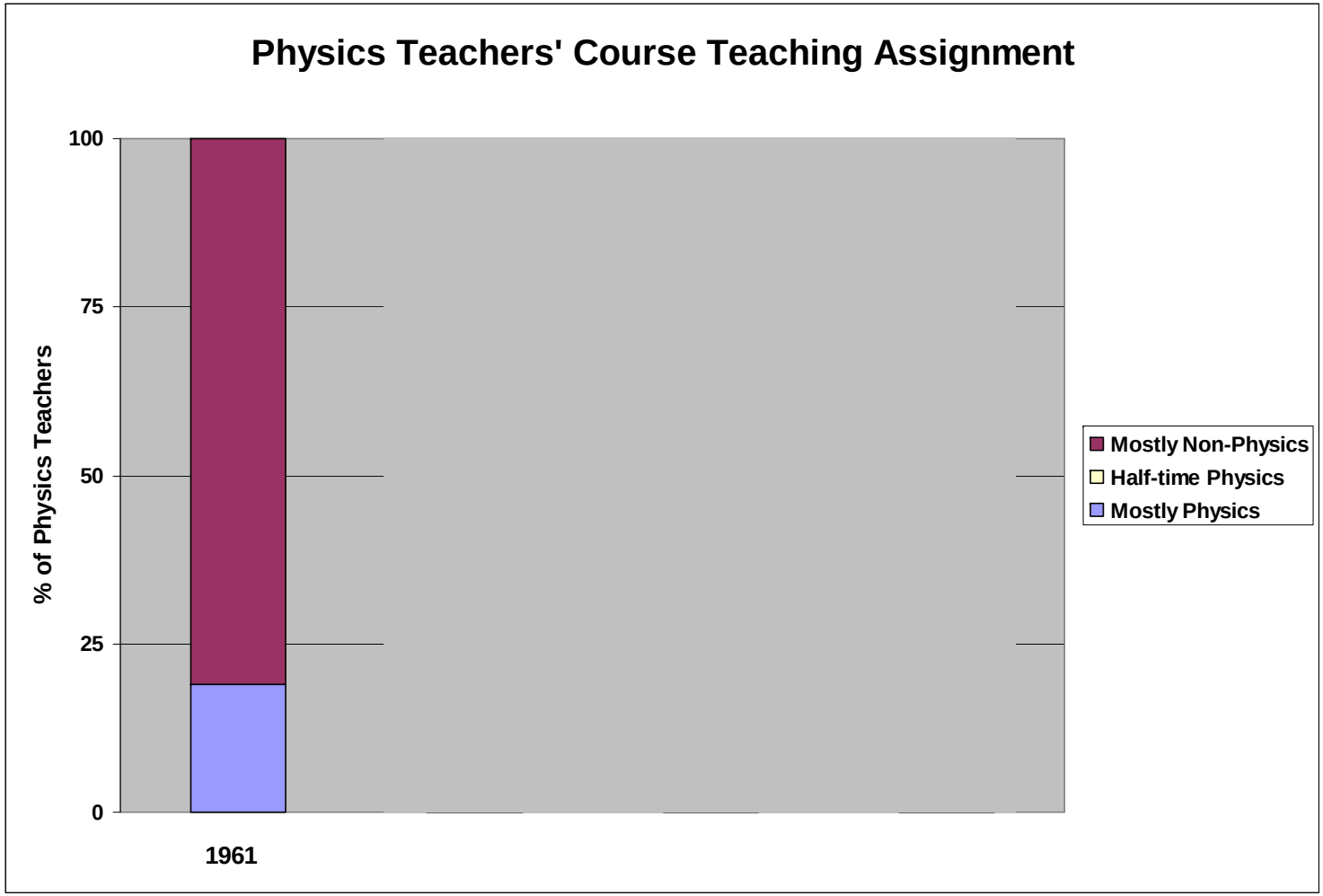


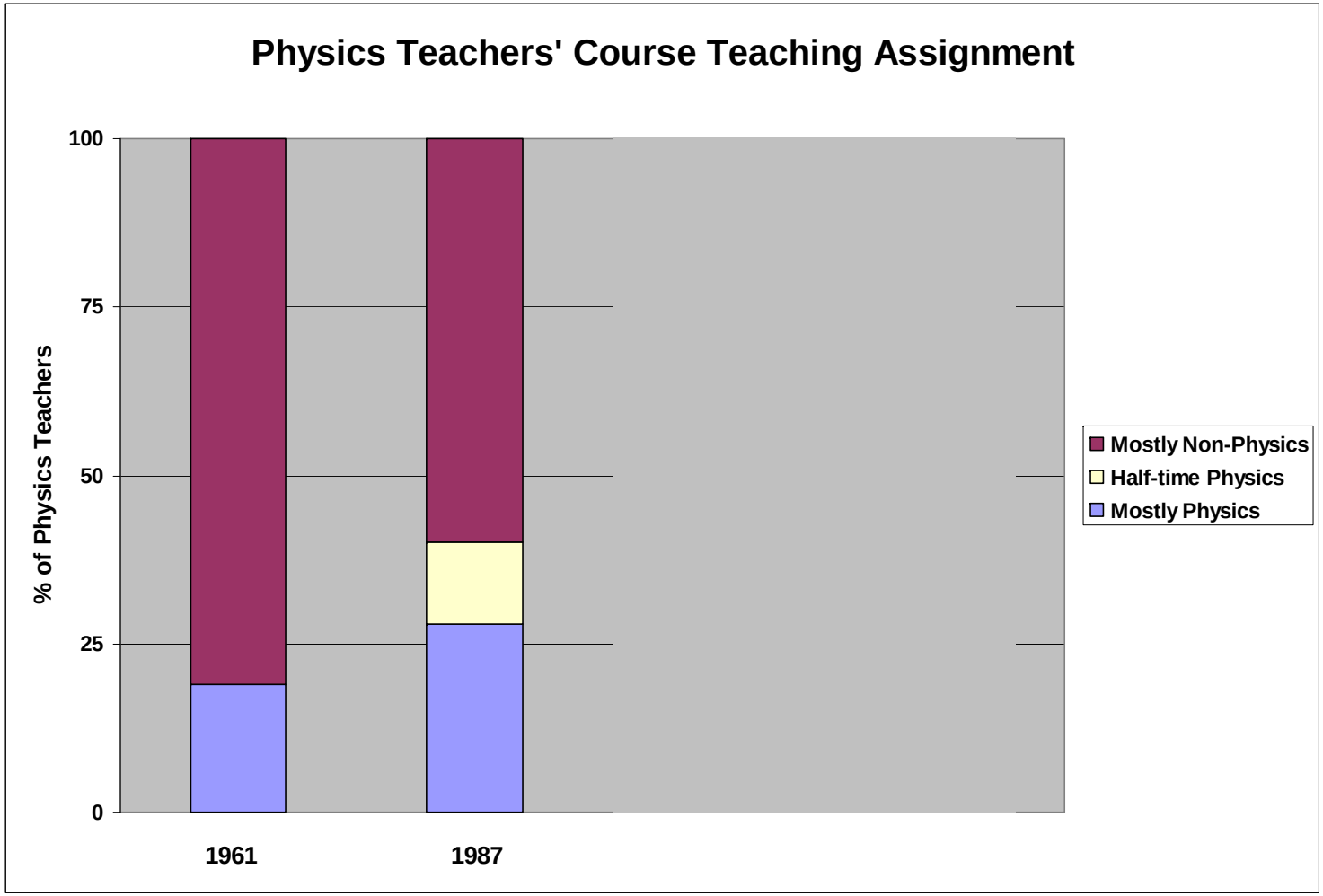
Estimated, from various sources

Physics Teachers Spend Most of Their Time Teaching Other Subjects

- In the 1920s, the average physics teacher taught two, three, or more *other* subjects.
- In 1961, more than 80% of U.S. physics teachers spent the *majority* of their time teaching other subjects.
- Most physics teachers taught a predominantly non-physics program until *2009*.



Source: AIP and NSF



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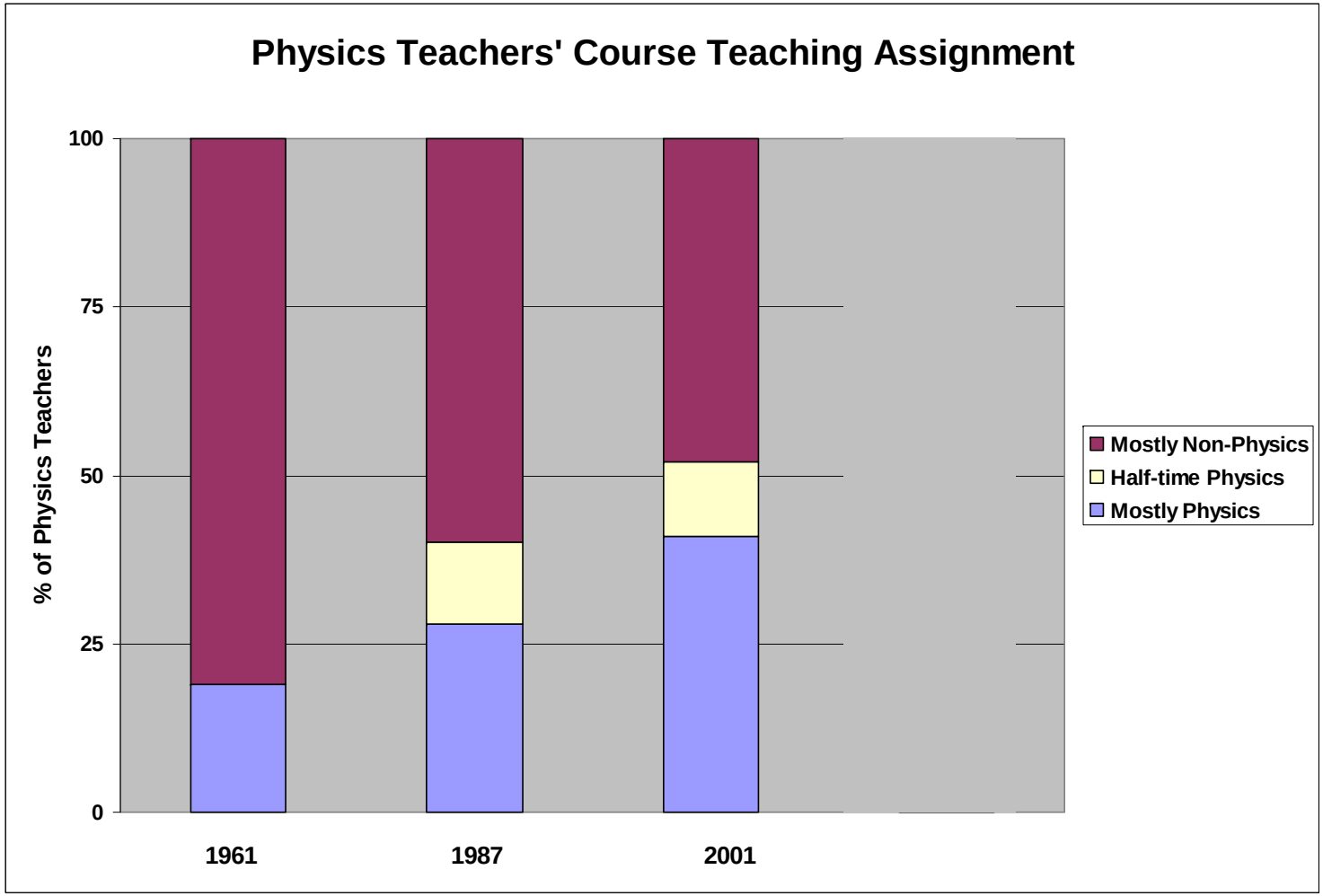

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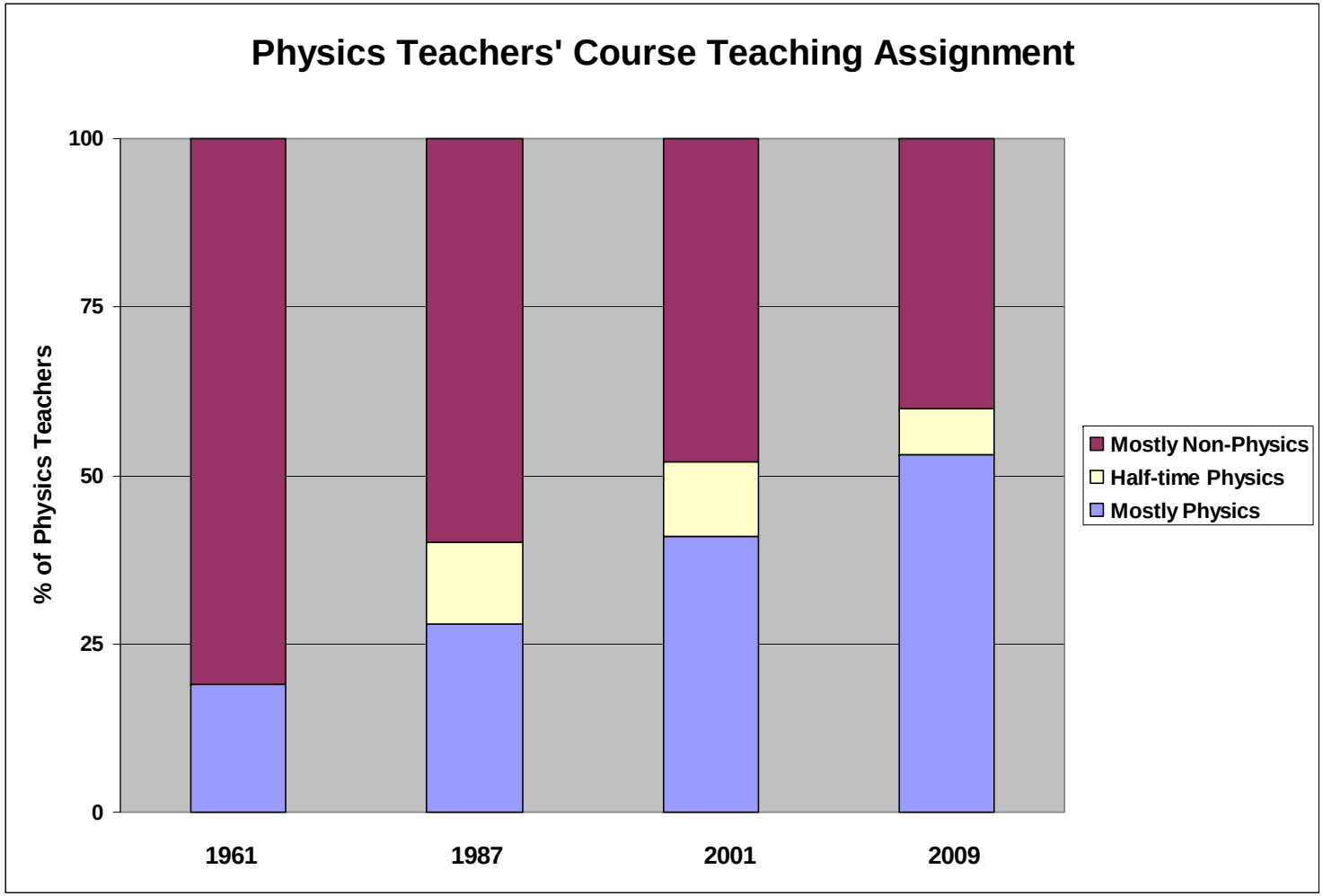

Source: AIP and NSF

Caution: Average Values Are Misleading

- There have always been enormous differences among the individual states
- Large schools in big cities have vastly more resources for physics teaching (*on average*) than small schools in rural areas
- Rapid year-to-year changes—especially during the early 1900s—created ever-moving targets for physics teacher educators

Courses for Physics Teachers

- Many (20-40%) teachers' colleges (current and former "normal schools") offered courses on physics pedagogy
- Significant numbers of state colleges and universities also offered such courses
- Little is known about the content of these courses

University of Chicago
Catalog 1909-1910

4. **Electricity, Sound, and Light.**—A general college course in Electricity, Sound, and Light, presented mainly from the experimental point of view, and involving the performance of eighteen laboratory exercises in electricity, four in sound, and six in light. Prerequisite: Physics 3. Mj. Summer Quarter, 2 sections, Associate Professors Millikan and Mr. Ham; Winter Quarter, 2 sections, Associate Professors Mann and Milliman; Spring Quarter, Associate Professor Kinsley.

5. **Lecture Demonstration Course.**—A course of lectures, demonstrations, and recitations supplementing courses 3 and 4 and completing a year's work in college Physics. Recent discoveries and developments in Physics are given especial attention. 5 hours a week. Prerequisite: Physics 4. Mj. Summer Quarter, Assistant Professor Gale; Spring Quarter, Associate Professor Mann.

6. **General Survey of Physical Science.**—A lecture demonstration course in which familiar physical phenomena are presented and discussed with reference both to their scientific interpretation and to their relations to modern life. Primarily for Arts students. Not accepted in satisfaction of specific requirements in Physics. Associate Professor Mann. [Not given in 1909–10.]

SENIOR COLLEGE COURSES

11. **Heat and Molecular Physics.**—A lecture course for advanced and graduate students, covering the Kinetic Theory, Capillarity, Elementary Thermodynamics, Solution, and Electrolysis. Prerequisite: Physics 4 and Calculus. Mj. Winter Quarter, Associate Professor Millikan.

12. **Light.**—A lecture course for advanced students covering the more important sections of geometrical and physical optics. [Not given in 1909–10.]

13. **Electricity and Magnetism.**—A course of advanced work in theoretical Electricity and Magnetism, intended to supplement the work in General Physics or to prepare for graduate work. Prerequisite: Physics 4 and Calculus. Associate Professor Kinsley. [Not given in 1909–10.]

14. **The Pedagogy of Physics.**—A course designed for teachers of Physics in high schools, consisting of lectures and discussions upon choice of subject-matter and methods of presentation best suited to elementary courses in Physics. Prerequisite: courses 3, 4, and 5, or equivalents. M. First Term, Summer Quarter, Associate Professor Millikan.

15. **Mechanics and Wave Motion.**—A lecture course on the physical meaning and the mathematical derivation of the fundamental equations of Mechanics and Wave Motion. Prerequisite: Physics 4 and Calculus. Mj. Autumn Quarter, 2:00, Assistant Professor Gale.

16. **Experimental Physics (Advanced): Molecular Physics and Heat.**—A course of advanced laboratory work involving the determination of vapor pressures and densities, coefficients of friction of gases and liquids, molecular electrical conductivities, freezing- and boiling-points, latent and specific heats, high and low temperatures, radio-active constants, etc. Prerequisite: course 4. Mj. Spring Quarter, Associate Professor Millikan.

17. **Experimental Physics (Advanced): Light.**—A course of advanced laboratory work in Light, consisting of accurate measurements in diffraction, dispersion, interference, and polarization. Prerequisite: course 4. Mj. Autumn Quarter, Associate Professor Mann.

18. **Experimental Physics (Advanced): Electricity and Magnetism.**—Laboratory work of the same grade as courses 16 and 17, but consisting of measurements in Electricity and Magnetism. Prerequisite: Mathematics 27 and Physics 4. Mj. Summer Quarter. Mj. Winter Quarter, Associate Professor Kinsley.

20. **Physical Manipulation.**—A series of exercises not provided in the regular courses of Experimental Physics, but important to the teacher or advanced student. It consists of the following groups:

Calculus. Mj. Winter Quarter, Associate Professor Millikan.

12. Light.—A lecture course for advanced students covering the more important sections of geometrical and physical optics. [Not given in 1909–10.]

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16. Experimental Physics (Advanced): Molecular Physics and Heat.—A course of advanced laboratory work involving the determination of vapor

UNIVERSITY OF COLORADO BULLETIN

Vol. XXII., No. 3. General Series No. 180.

Published Monthly by the Regents of the University of Colorado.
Entered at the Post Office, Boulder, Colorado, as second-class mail matter.

CATALOGUE, 1921-1922

BOULDER, COLORADO, MARCH, 1922.

3. ANALYTICAL MECHANICS—STATICS. Spring quarter. 3 h. Taken regularly in the sophomore year.

A study of the conditions of equilibrium of particles and rigid bodies; centers of mass; moments of inertia.

Prerequisites: Course 1 and calculus; open, however, to those taking the integral calculus.

4. ANALYTICAL MECHANICS—DYNAMICS. Autumn and winter quarters. 3 h. Taken regularly in the junior year.

A study of the motion of particles and rigid bodies. Emphasis is laid upon the fundamental physical principles of the subject and an attempt is made to give the student a certain facility in translating physical conceptions into mathematical symbols and mathematical formulae into physical ideas.

Prerequisites: Course 1, and calculus.

5. TEACHERS' TRAINING COURSE IN PHYSICS. Spring quarter. 3 h.

A course designed primarily for those who expect to teach physics in secondary schools. Such topics as the proper arrangement and aims of a secondary-school course, laboratory equipment and instruction, and ways and means of teaching the various subjects, will be considered in lectures, discussions, and reports. The teaching of General Science will also be discussed. Considerable outside reading will be required.

Prerequisites: Courses 1 and 2 or their equivalent.

6. THEORY OF ELECTRICITY AND MAGNETISM I. Autumn quarter, M. W. 11:00. 2 h. Winter quarter, M. W. F. 11:00. 3 h.

Taken regularly in the junior year.

The elements of the mathematical theory of electricity and magnetism with applications to the general theory of instruments of fundamental importance in electrical measurements.

Prerequisites: Courses 1, 3, 4, and calculus; open, however, to those who are taking Course 4.

quarters. 3 h. Taken regularly in the junior year.

A study of the motion of particles and rigid bodies. Emphasis is laid upon the fundamental physical principles of the subject and an attempt is made to give the student a certain facility in translating physical conceptions into mathematical symbols and mathematical formulae into physical ideas.

Prerequisites: Course 1, and calculus.

5. TEACHERS' TRAINING COURSE IN PHYSICS. Spring quarter. 3 h.

A course designed primarily for those who expect to teach physics in secondary schools. Such topics as the proper arrangement and aims of a secondary-school course, laboratory equipment and instruction, and ways and means of teaching the various subjects, will be considered in lectures, discussions, and reports. The teaching of General Science will also be discussed. Considerable outside reading will be required.

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- Little is known about the content of these courses

However: *Enrollments were apparently very small: Extremely few "trained" physics educators were produced*

Physics Teacher Education Programs Are Scarce and Produce Very Few Graduates

- **1881:** "…the difficulty of finding trained teachers or teachers with whom science was not subordinate to other things…is real enough…." *[Report on the Teaching of Physics and Chemistry]*

"…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

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- **1946:** "[There is] a deficiency in the number of well-trained science teachers in the secondary schools." *[AAPT]*

- **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." *[National Academy of Sciences]*

1968: Panel on the Preparation of Physics Teachers (AAPT/AIP) issues report on physics teacher education:

"…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.…

"…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...."

[AAPT/AIP, *Preparing High School Physics Teachers* (1968), p. 5]

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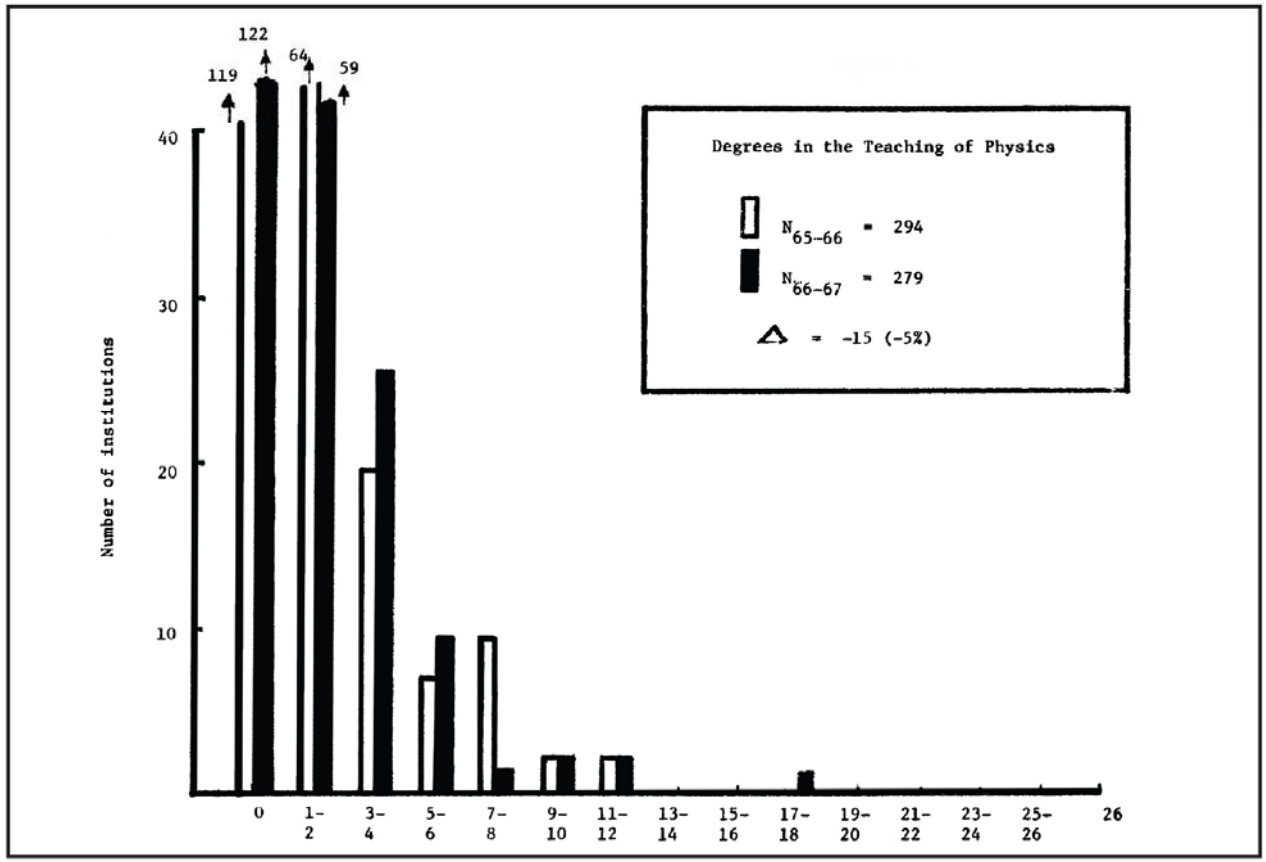
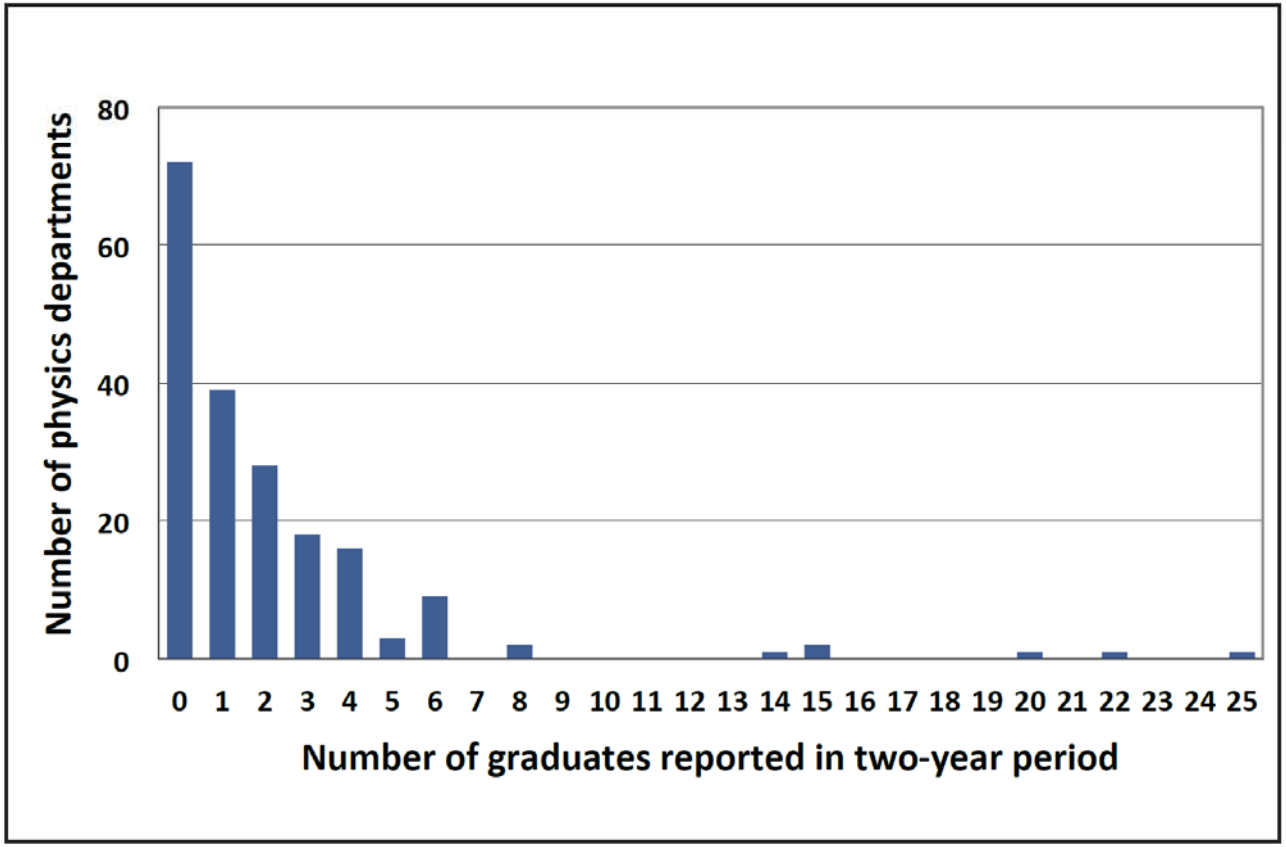
- **2013:** "…the physics community is not producing enough highly qualified physics teachers to meet the growing need at the high school level." *[National Research Council of the National Academies]*

Distribution of Physics Teacher Graduates from U.S. Institutions, 1965-1967



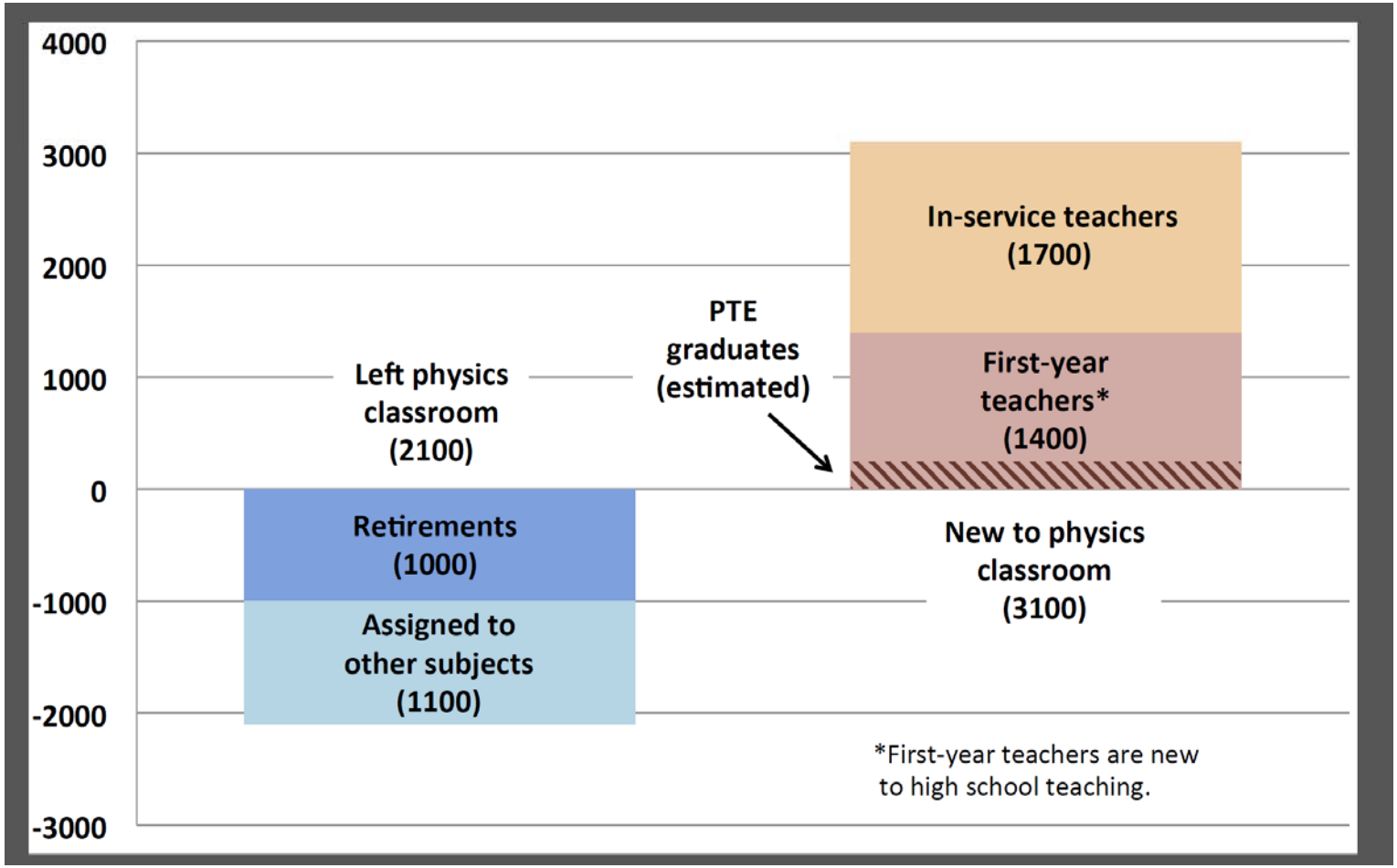
Newton and Watson, *Research on Science Education Survey* (1968), p. 26

Distribution of Physics Teacher Graduates from U.S. Institutions, 2007-2009



Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), p. 14

Physics Teacher Annual Turnover



Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), p. 17

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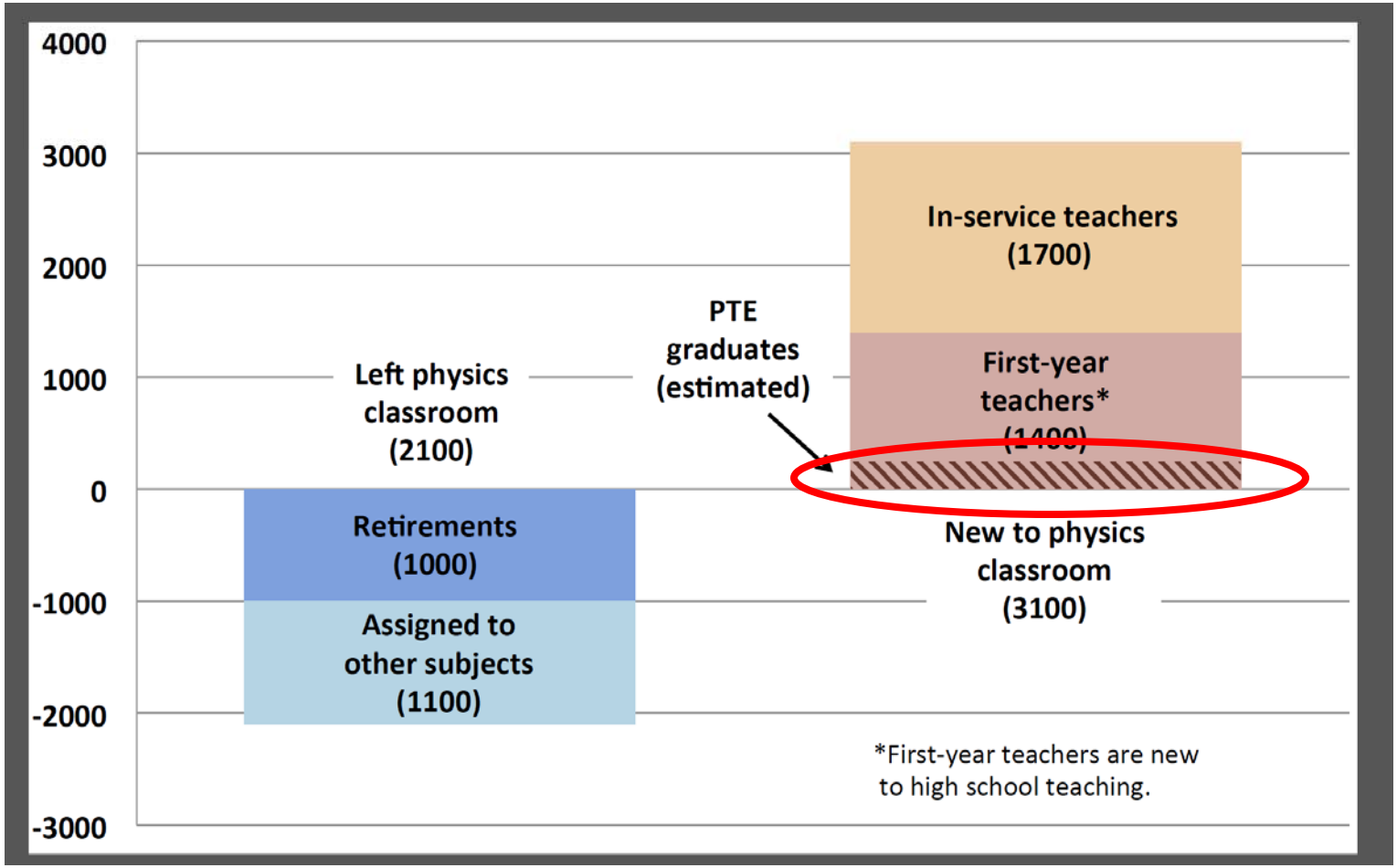

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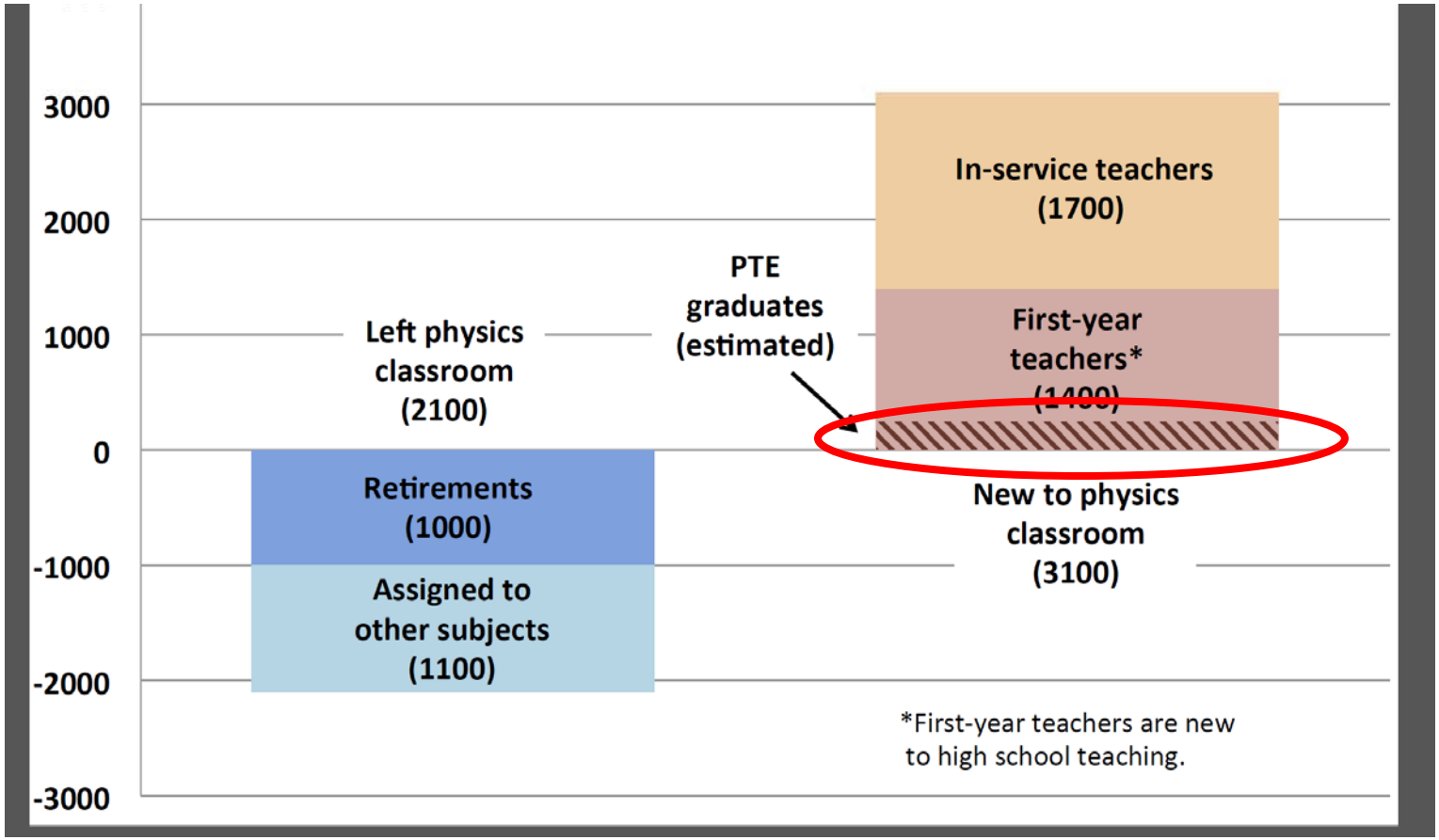
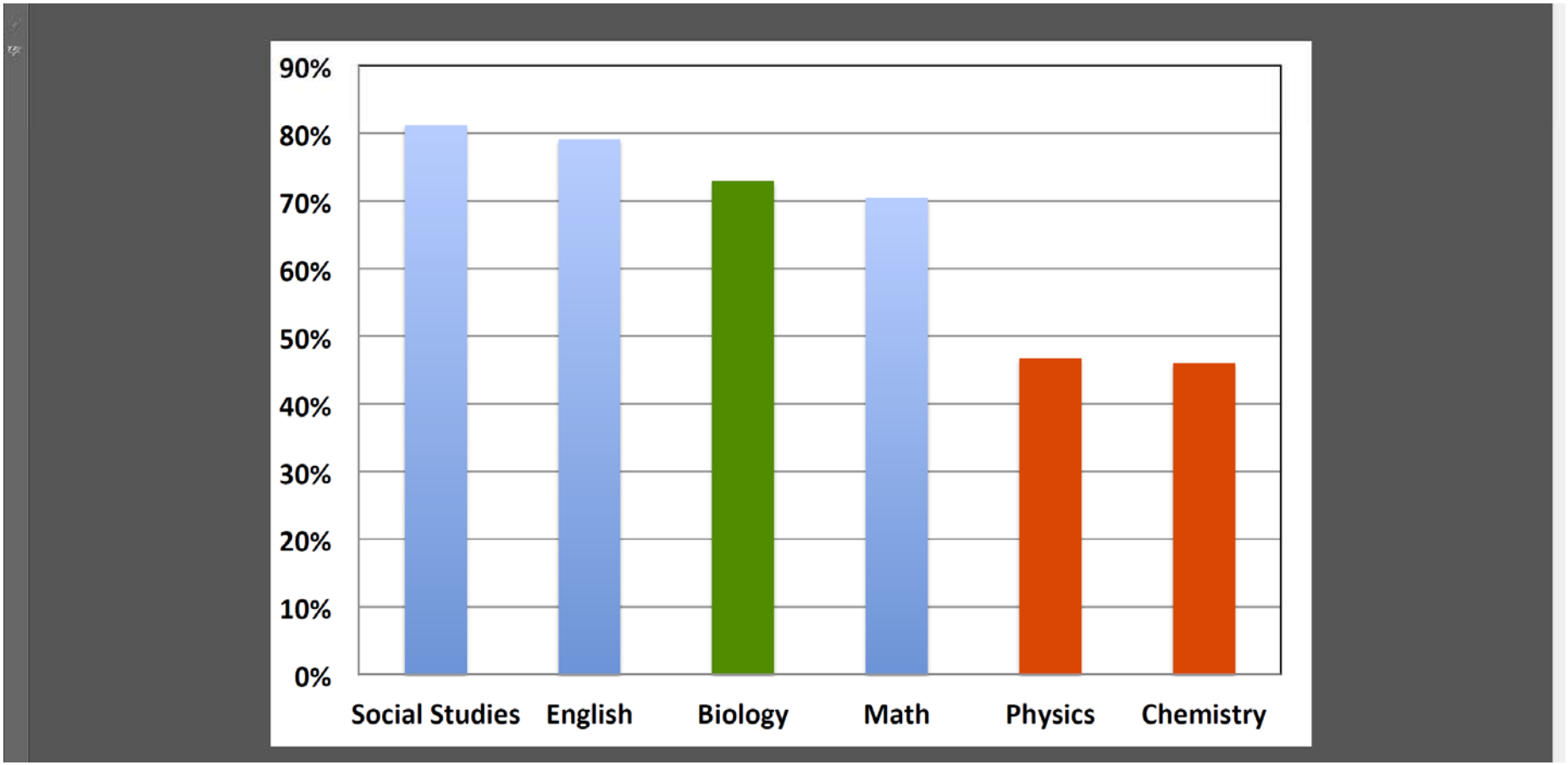
Physics Teacher Education programs produce an *insignificant* fraction of new physics teachers



Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), p. 17

Fraction of High School Classes Taught by Teacher with Degree in Subject



Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), p. 2

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]

From 1880-2014, Most Physics Teachers Have Had Inadequate Preparation

- State certification requirements vary wildly from state-to-state, and in most cases fall far short of physics-community recommendations.
- There are many routes available for evading certification standards, and many local incentives for doing so.
- Since most states and colleges have not required physics for graduation or entrance, there has been only limited real demand for highly trained physics teachers (despite complaints of shortages).

Summary

- The preparation recommended for physics teachers is demanding and time-consuming, and difficult to supplement with similar levels of preparation in another teaching field.

- Since physics is a one-year non-required course taken by a minority of students, there has always been low demand for well-qualified, specialized physics teachers.

- For over a century, clear warnings of physics teacher shortages and explicit recommendations for addressing the shortages have yielded only limited and uneven progress towards improvements.