Forgetting History and Other Reasons Change is Hard: Structural Barriers

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In collaboration with Valerie K. Otero

Why Change is Hard: Structural Barriers

Outline

I. Too much to teach, too little time

II. Can’t teach what you don’t know

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“There is probably no highly civilized country in the world in which the average student is not given more thorough training in these fundamental sciences [‘physics, chemistry, and biology, with the strongest emphasis thrown upon the physics’] than in the United States” [1916]; “The expanding of the curriculum and the consequent *subject pressure* have crowded out the sciences because they have been put up in tabloid form instead of being made a sequence and welded together into a systematic and thoroughgoing course, as is mathematics or the languages, and hence they have been most easily pushed off the educational platter….” [1917]

R. A. Millikan, U. Chicago, “The elimination of waste in the teaching of high school science” (1916) and “Science in the secondary schools” (1917)

Structural Barrier: Physics is a One-year Course

- Long ago, U.S. high school physics was institutionalized as only a one-year course
- A large and expanding curriculum had to squeeze into a time too short to contain it
- Relatively little teaching of physics resulted in little demand for physics teachers
- All subsequent reform efforts have operated within this century-old constraint

The Evolving Role of the Physics Course

- Physics (as “Natural Philosophy”) was an integral part of the curriculum of the earliest private secondary “academies” (in the late 1700s) and the first public high schools (in the early 1800s).
- Physics was originally taught as a “how things work” course, typically occupying less than a year
- Teaching of physics was widespread, incorporated in the great majority of secondary curricula, but no one was trained as a “physics teacher”

Physics becomes "Hands-on"

- Around 1880, physics teaching in high schools *and* colleges began to incorporate student laboratory activities to a significant degree.
- High school physics was "officially" recognized as a one-year lab-centered course, along with other sciences.
- A small community of science teachers developed and aspired to broad goals for physics courses, including improving observational and reasoning skills.
- Despite strong support from teachers, physics instruction was never formally incorporated in elementary grades (K-8) curriculum.

Too Much to Teach, Too Little Time

- There has been continual variation in the physics curriculum: alteration and expansion of topics taught, and of teaching goals
  - 1860s, “information”; 1890s, “observation,” 1900s, mathematical problem solving, 1930s, “everyday life,” 1960s, conceptual depth; 1990s, modern physics
- Essentially no change in instructional time: physics still a one-year high-school course (with very limited instruction in K-8)
- Little teaching time → limited teacher demand

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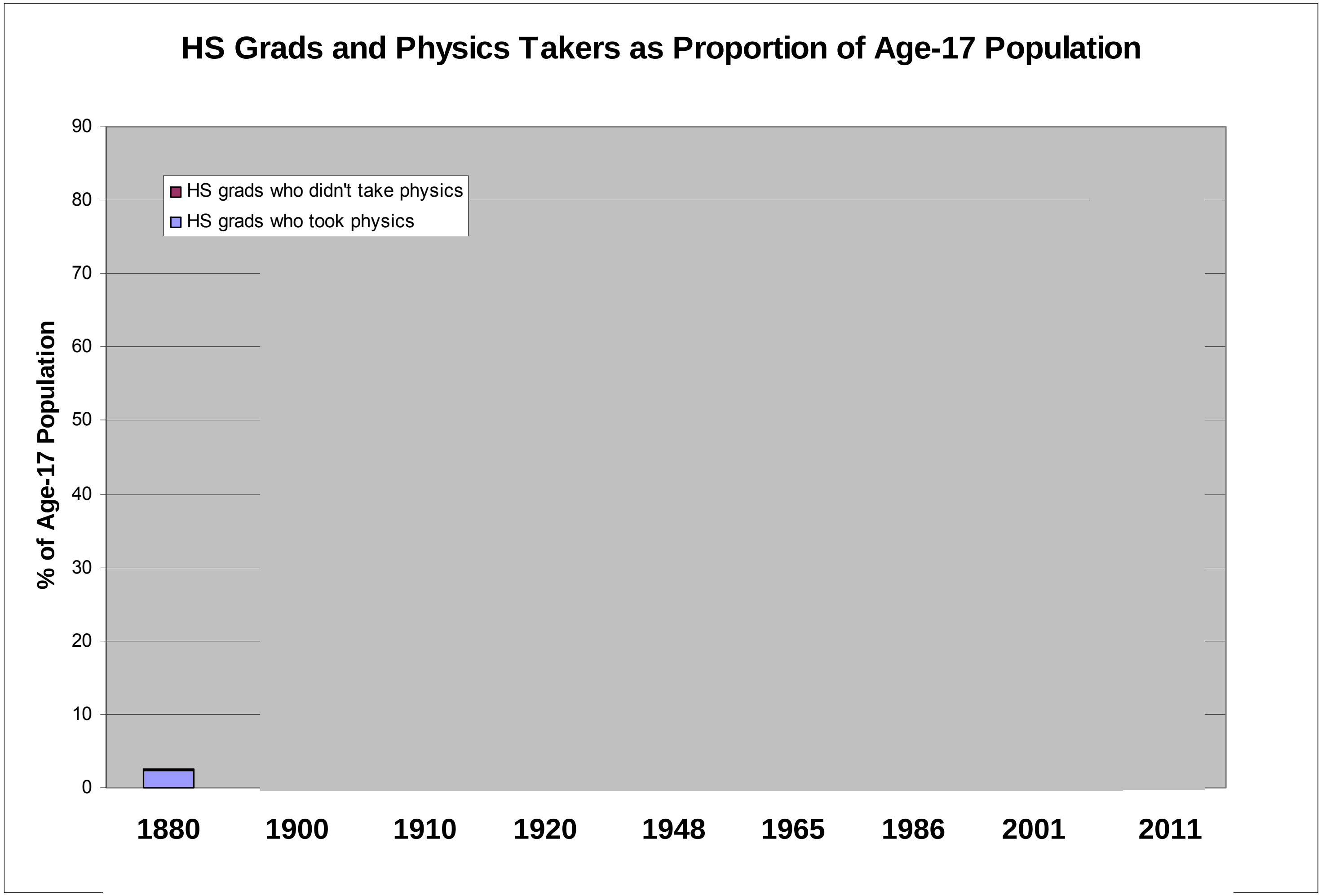
N. Henry Black, Harvard U., "The training of science teachers, here and abroad" (1931)

Early Days (Before 1910)

- Total high school enrollment was low, but growing; however:
- Most (> 90%) high schools were *very* small and did not have specialist physics teachers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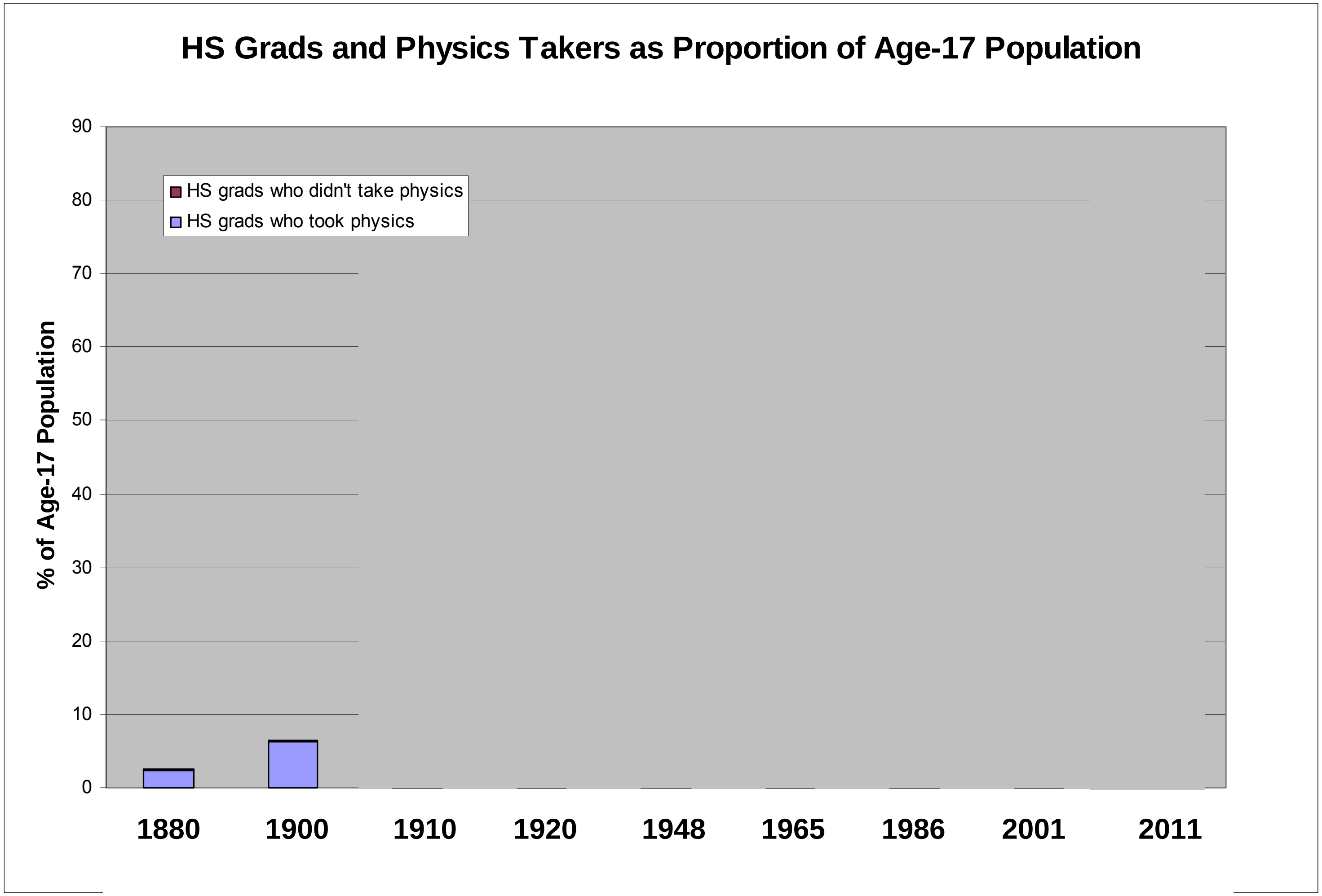
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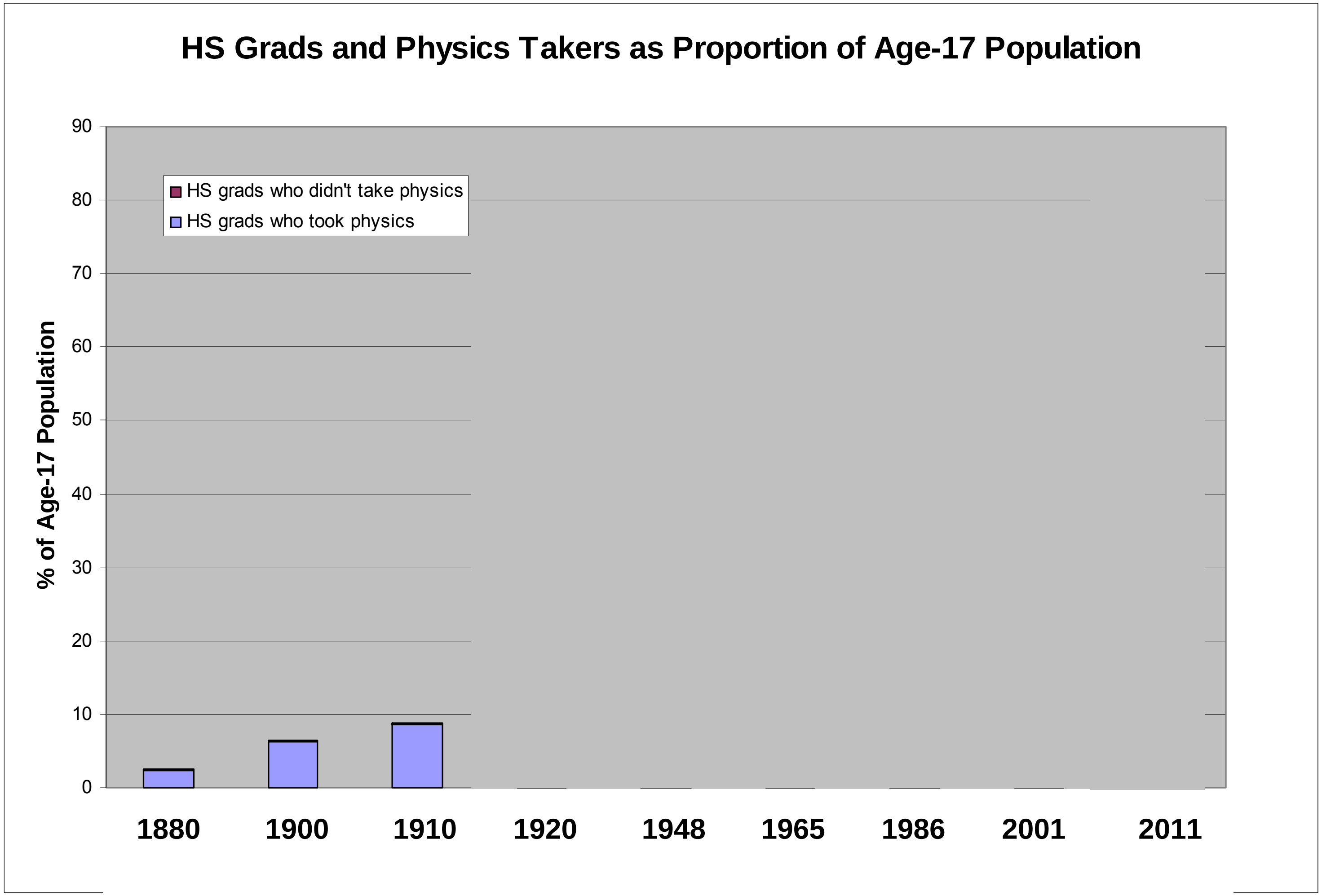
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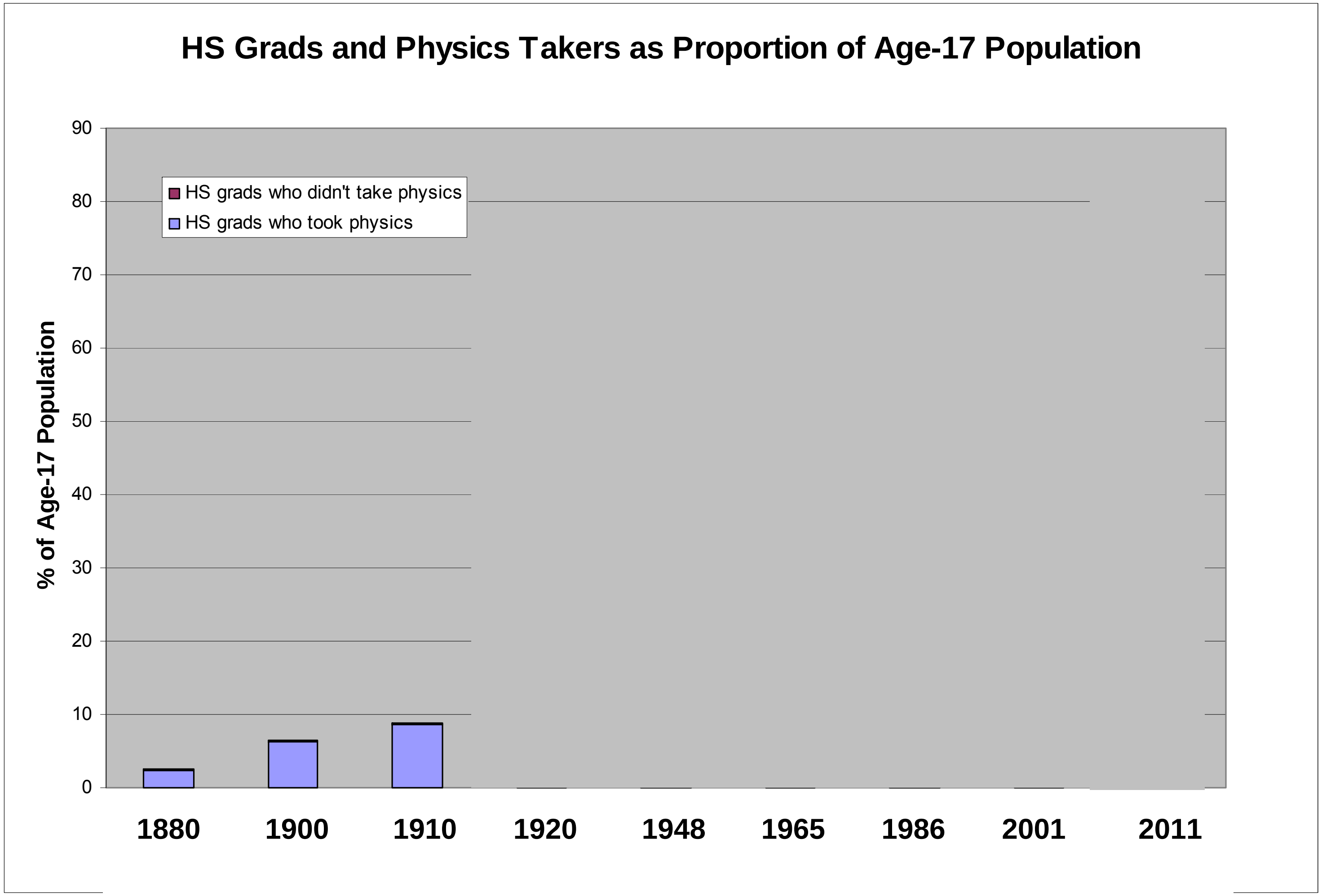
Expansion in High School Enrollment (≈1900-1950)

- Enrollment grew, at the same time as…
- Elective system introduced and college entrance requirements loosened → Sharply decreasing percentage of high school graduates took physics, so:
- Physics declined in importance in overall HS curriculum
- Many (> 90%) high schools were *still* very small and did not have specialist physics teachers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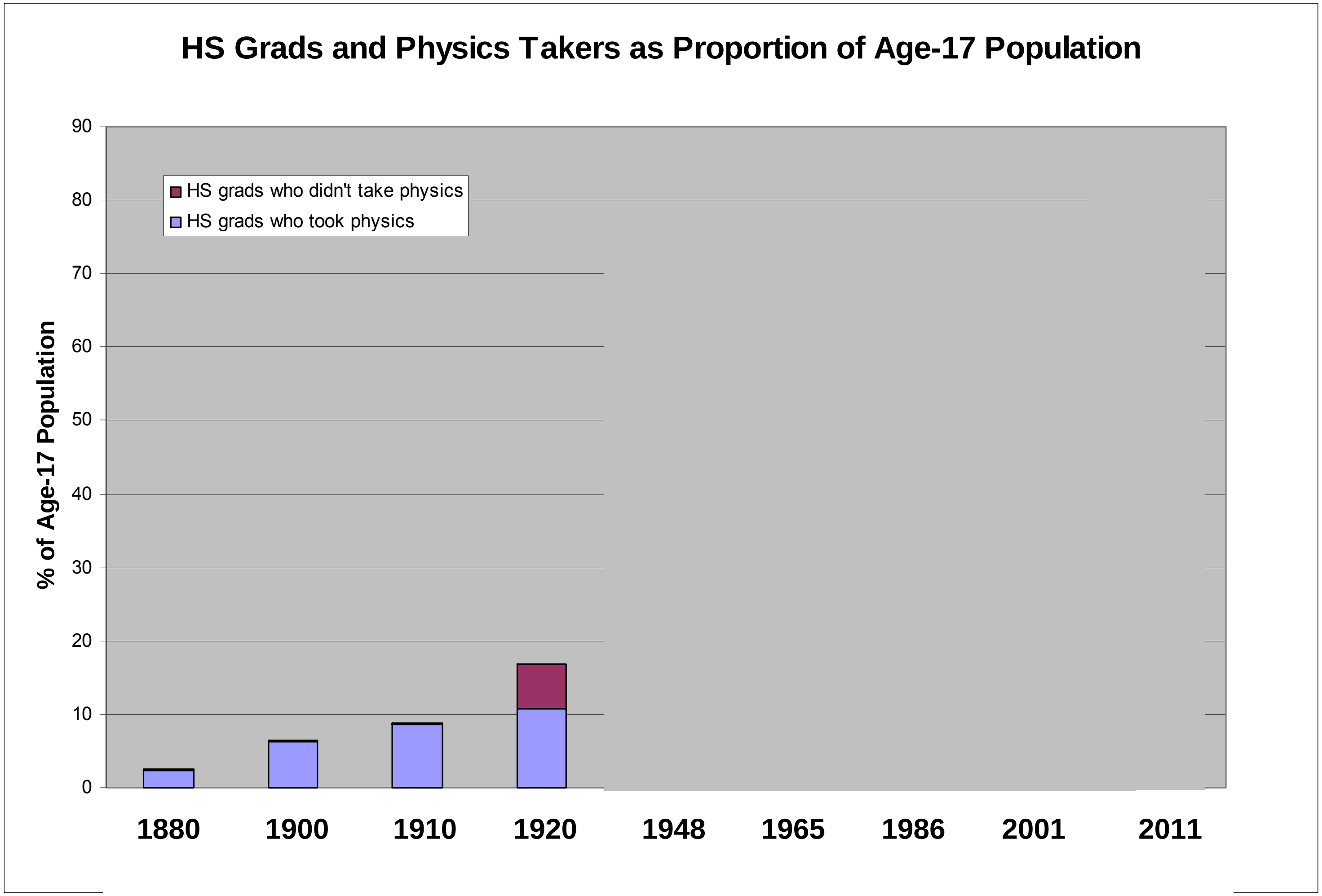
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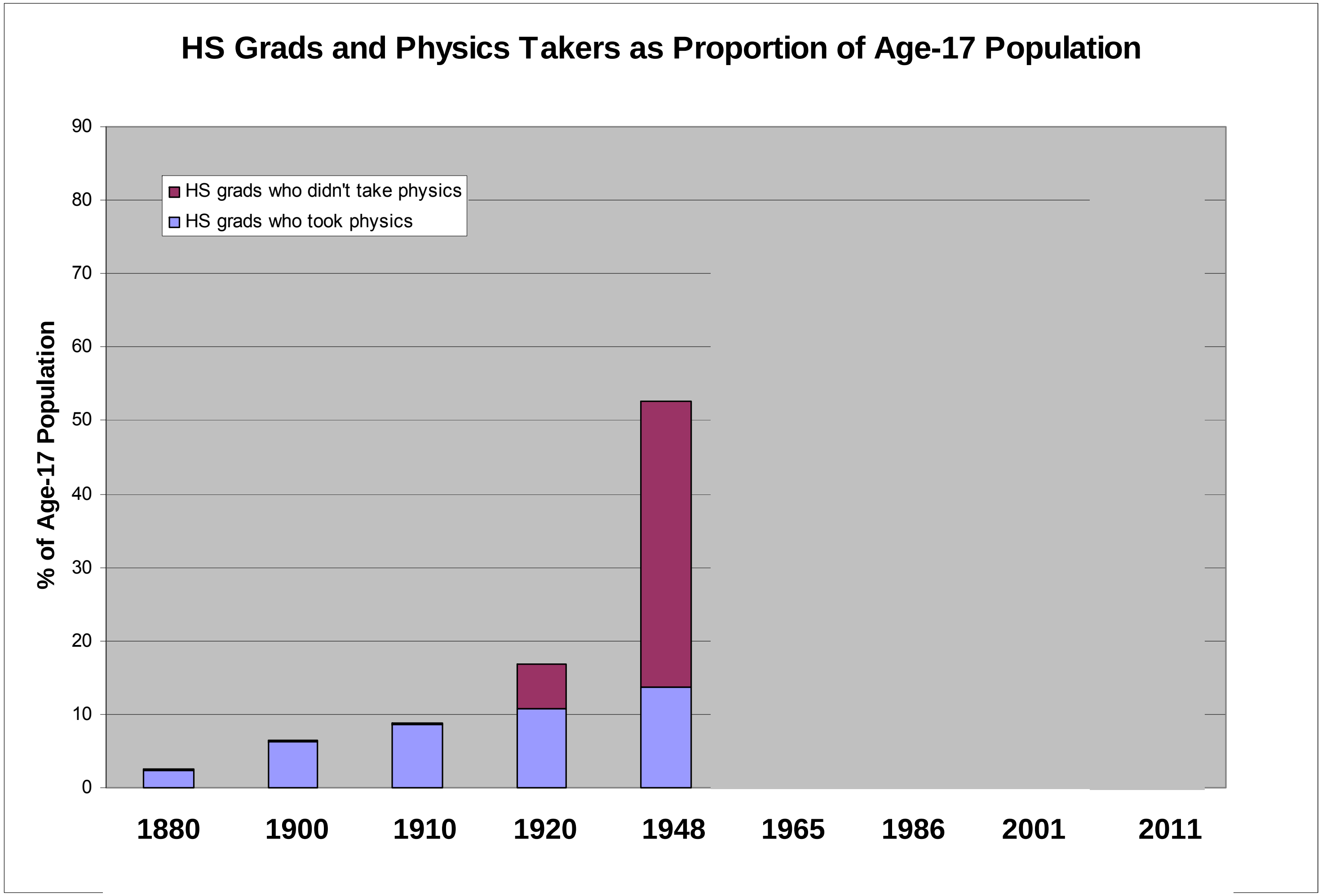

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Primary Constraints

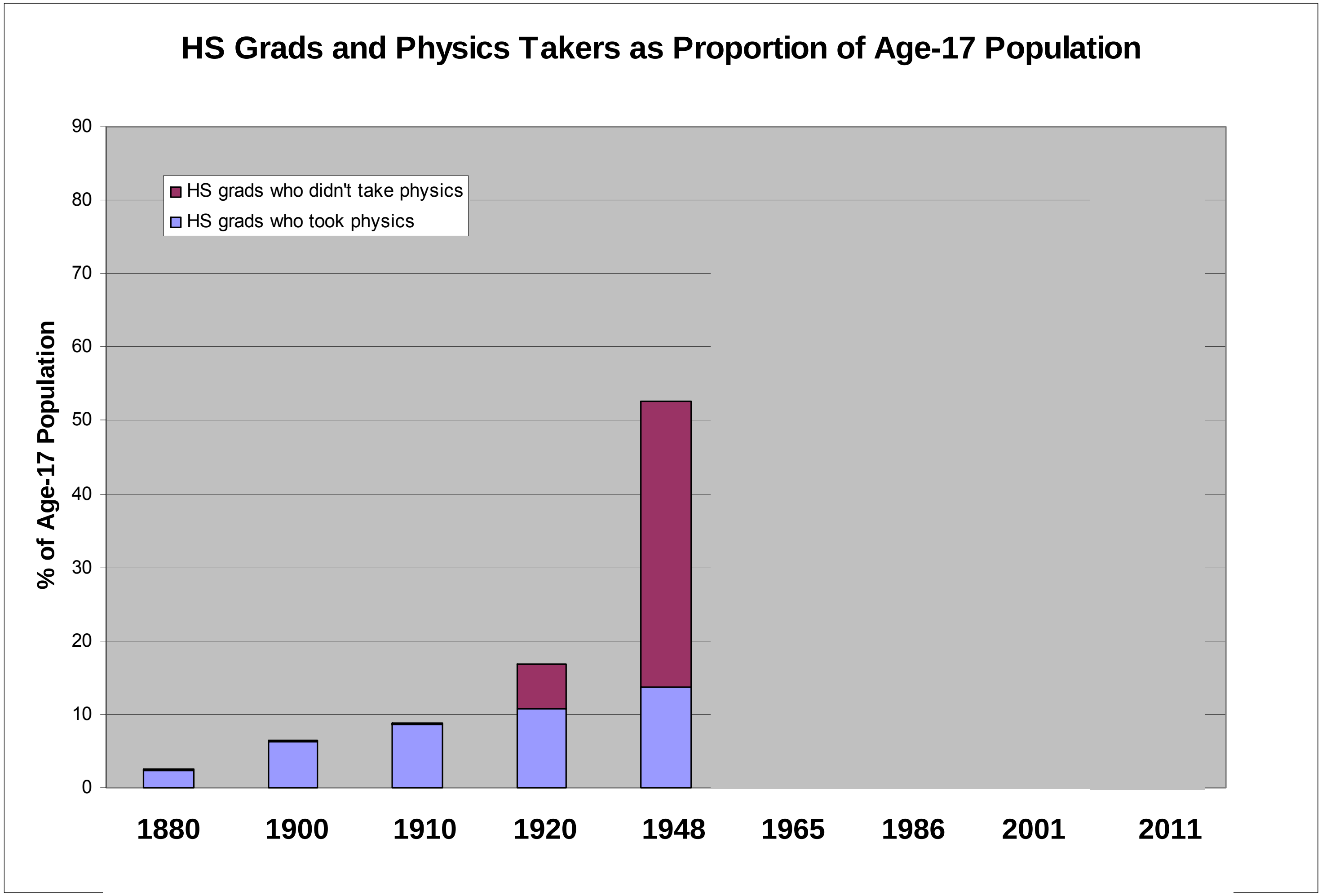
- Persistent large proportion of very small schools
- Physics taught only as one-year course, for third- or fourth-year students (no gradual “easing in” to college-prep physics courses in early grades)
- College and high school requirements for physics were (mostly) eliminated around 1900

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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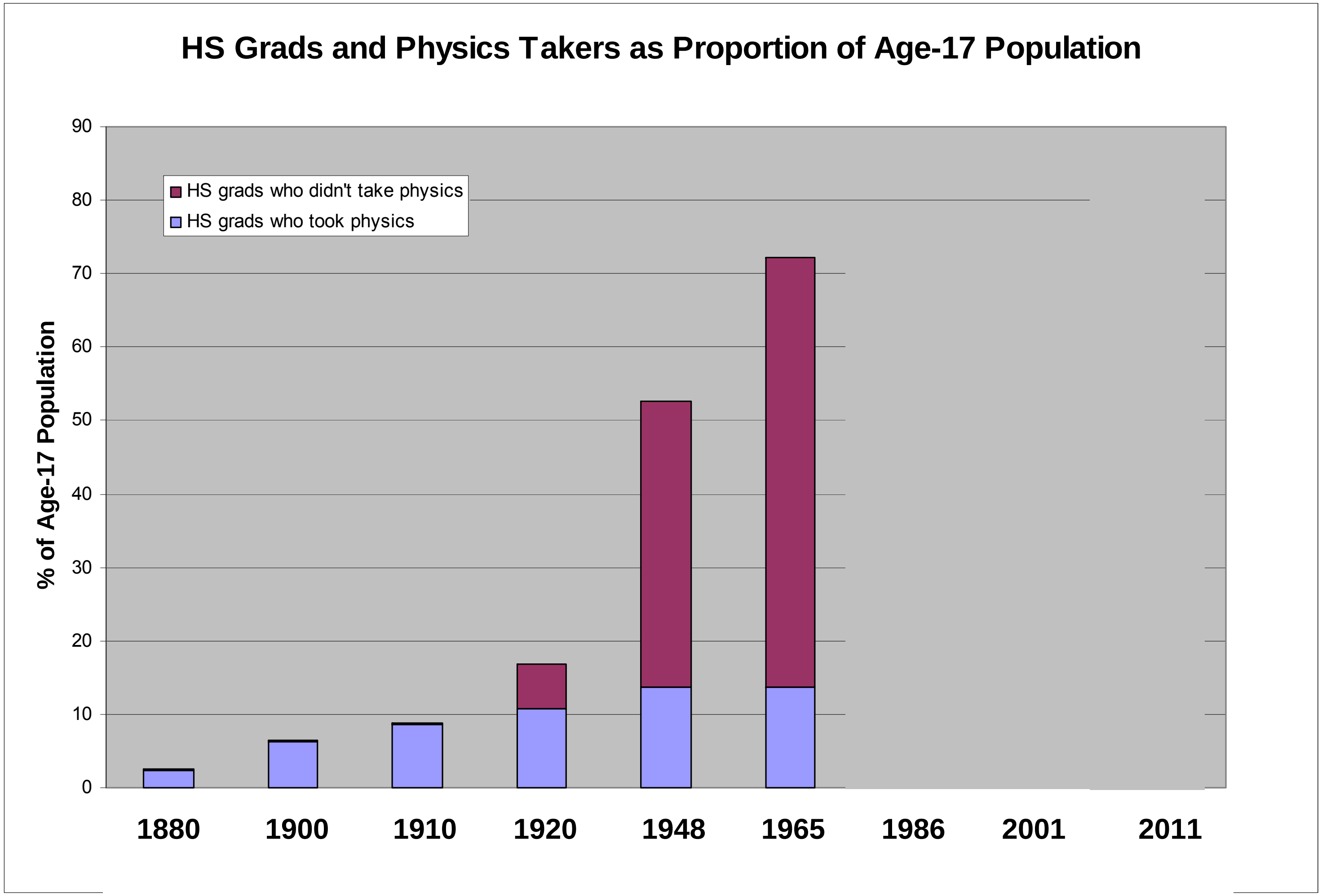
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Structural Barriers

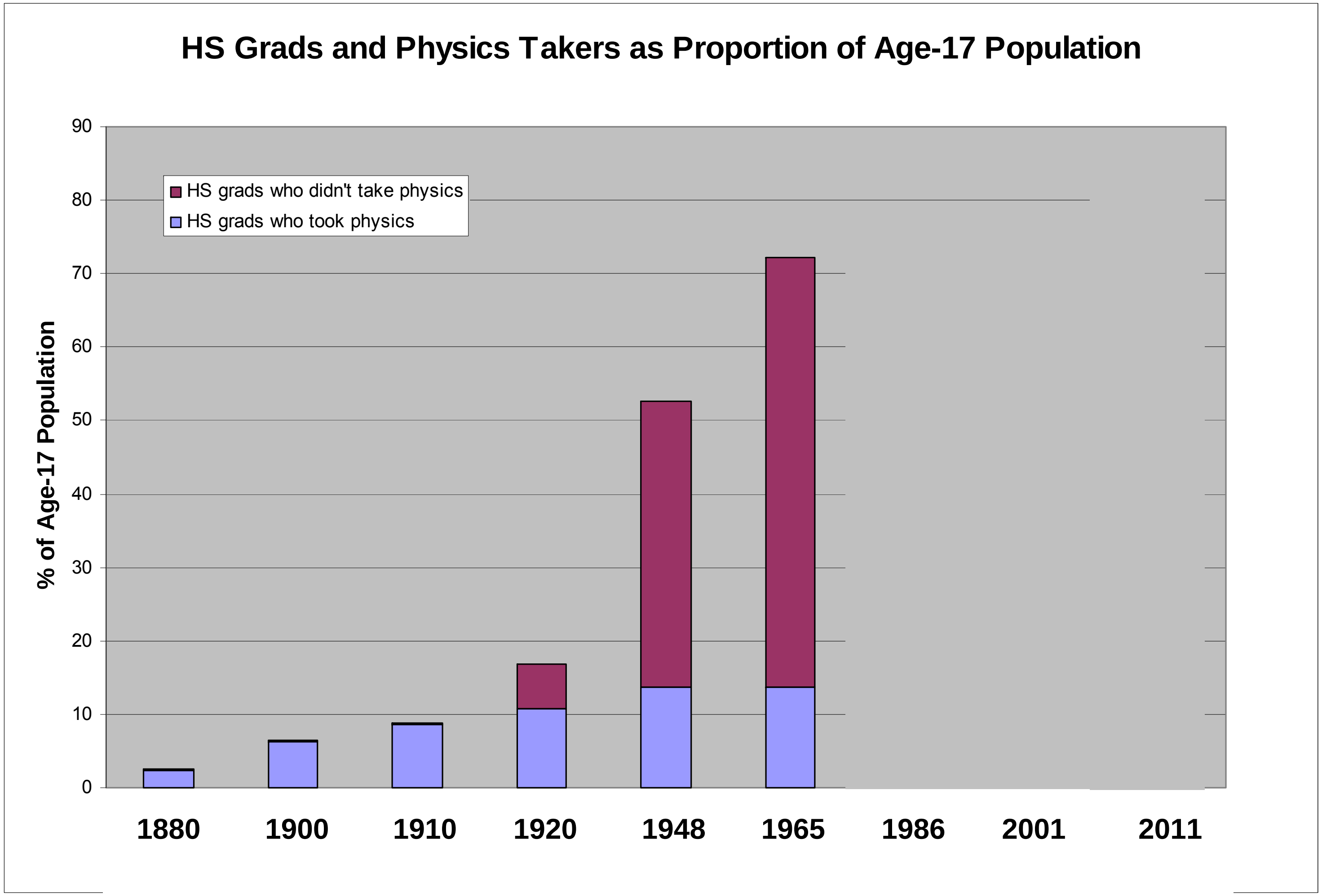
- Summer institutes were *not sufficient* to get unprepared teachers ready to teach hands-on, inquiry-based physics.
- Despite enormous development efforts, the new curricula were not based on research on student learning, and were *poorly tuned* to most of the primary constituency.
- Even a radical revision of a one-year course *could not replace* a multi-year sequence.
- States and school districts were *not willing* to engage in large-scale science reform that had no obvious payoff.

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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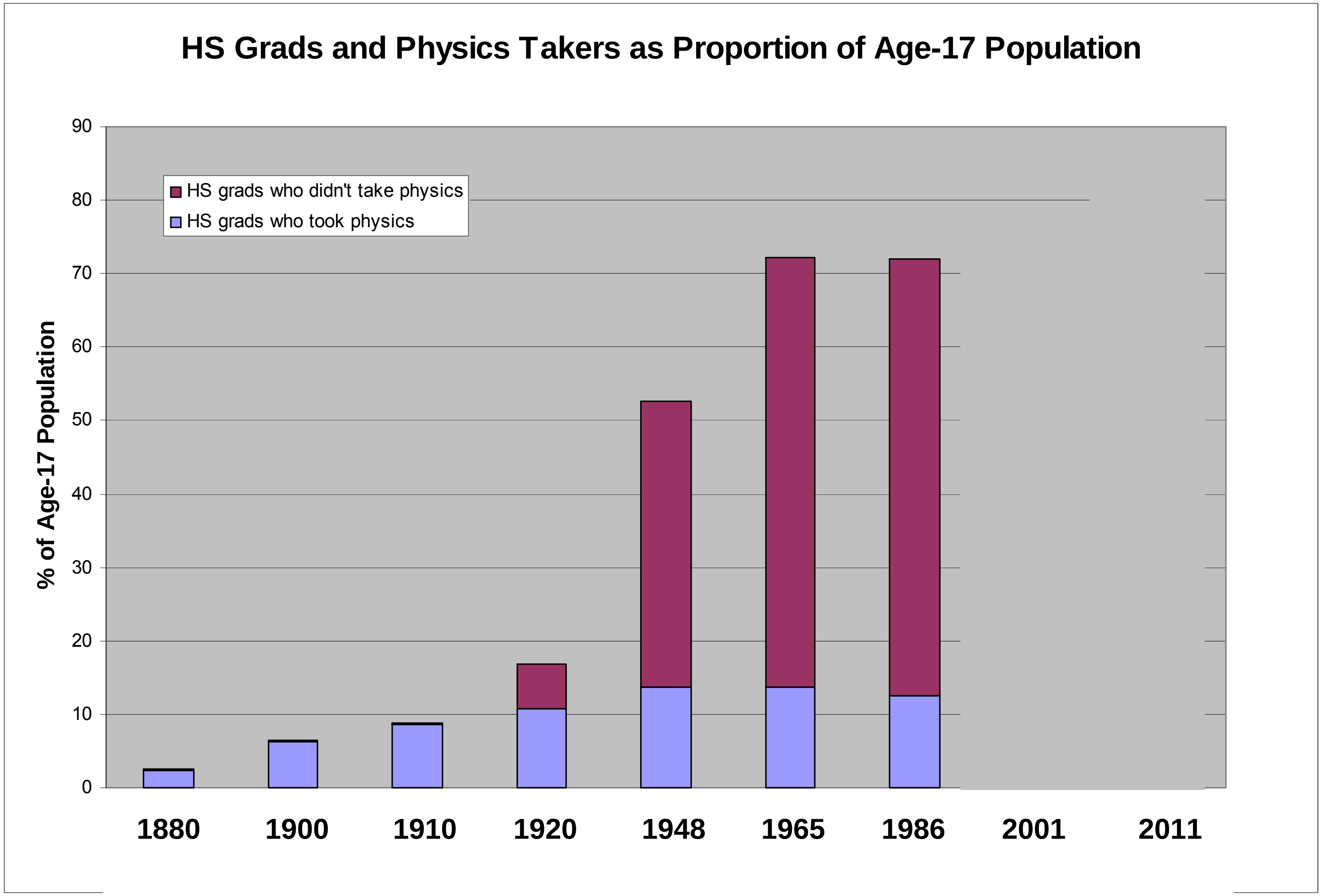
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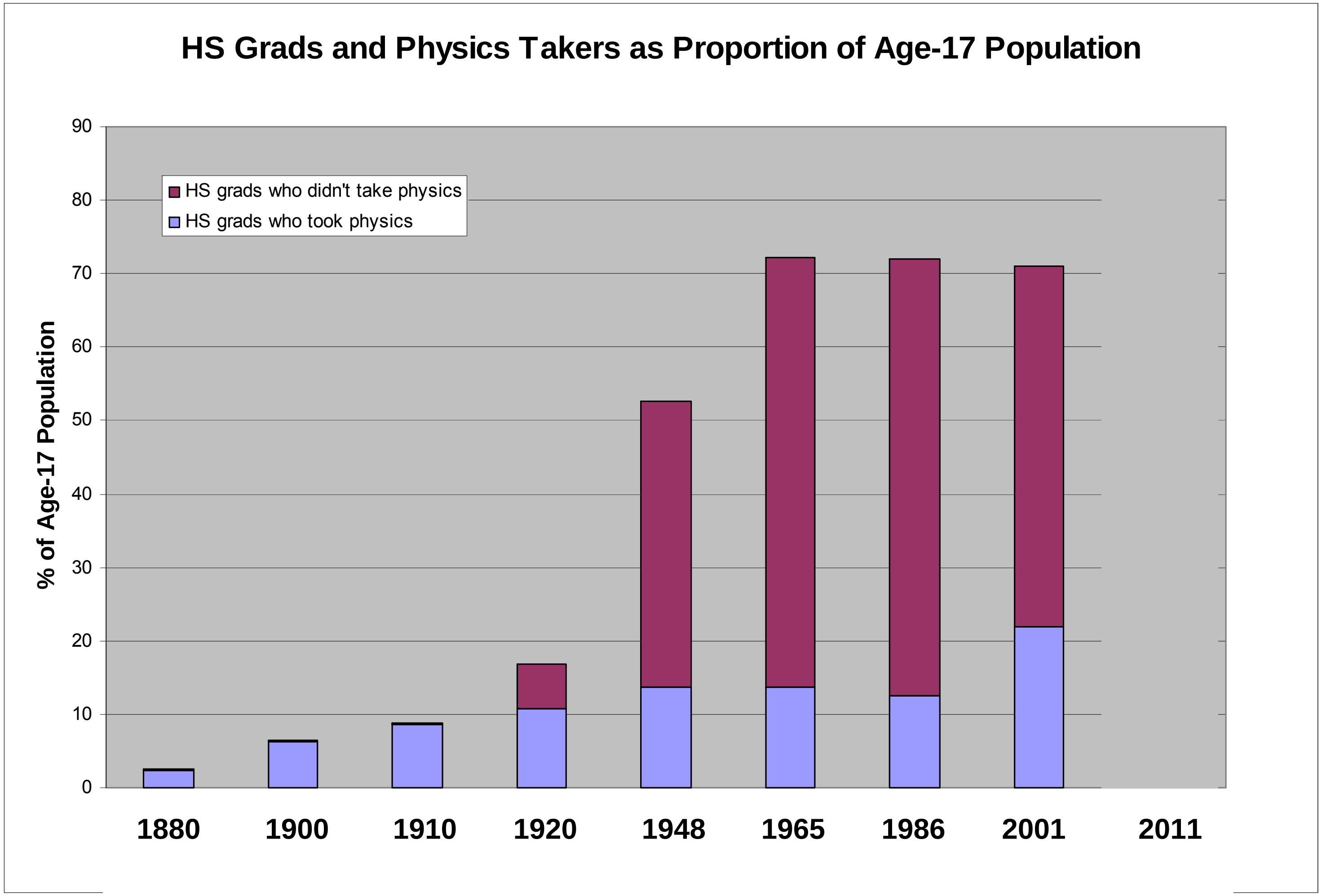
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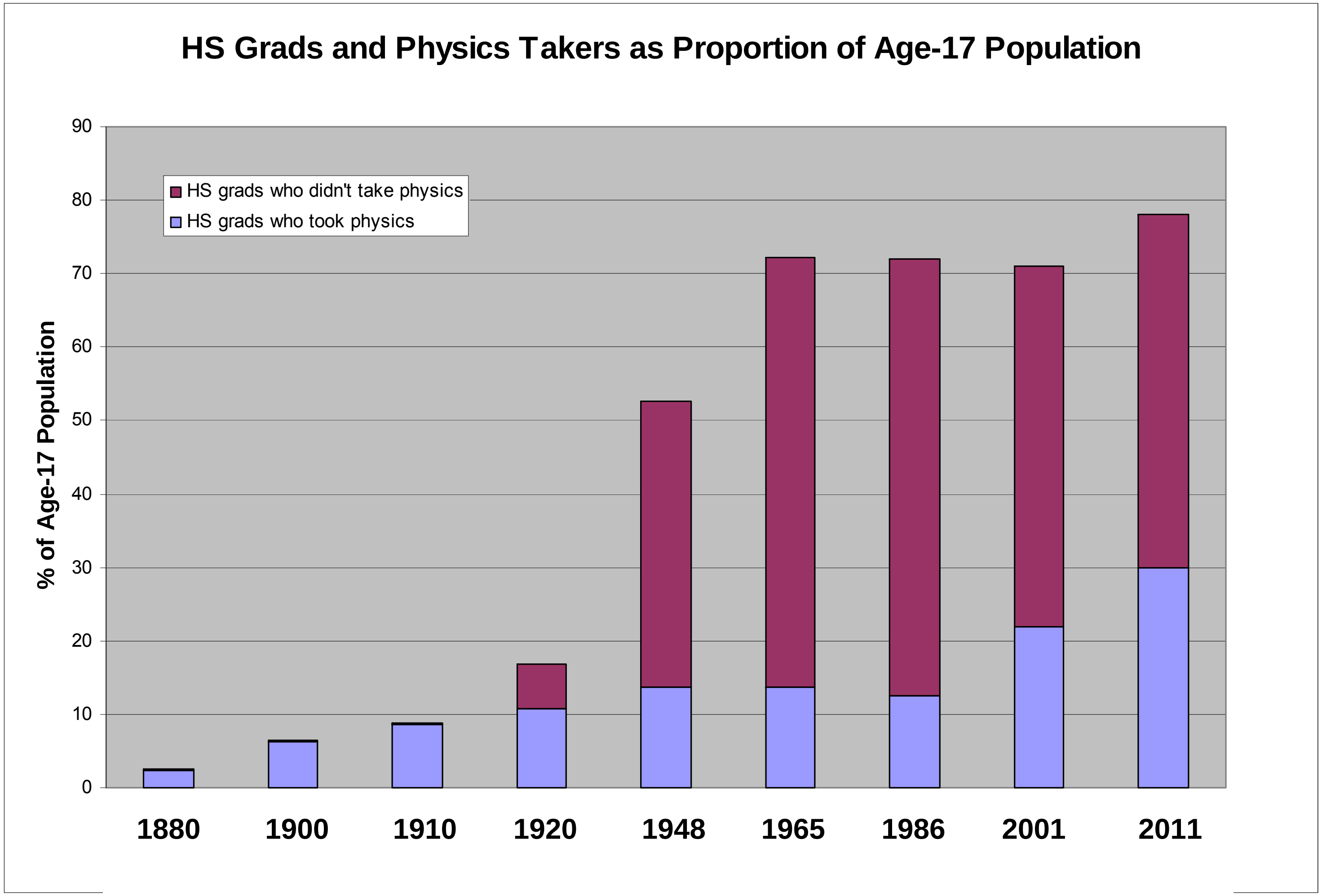

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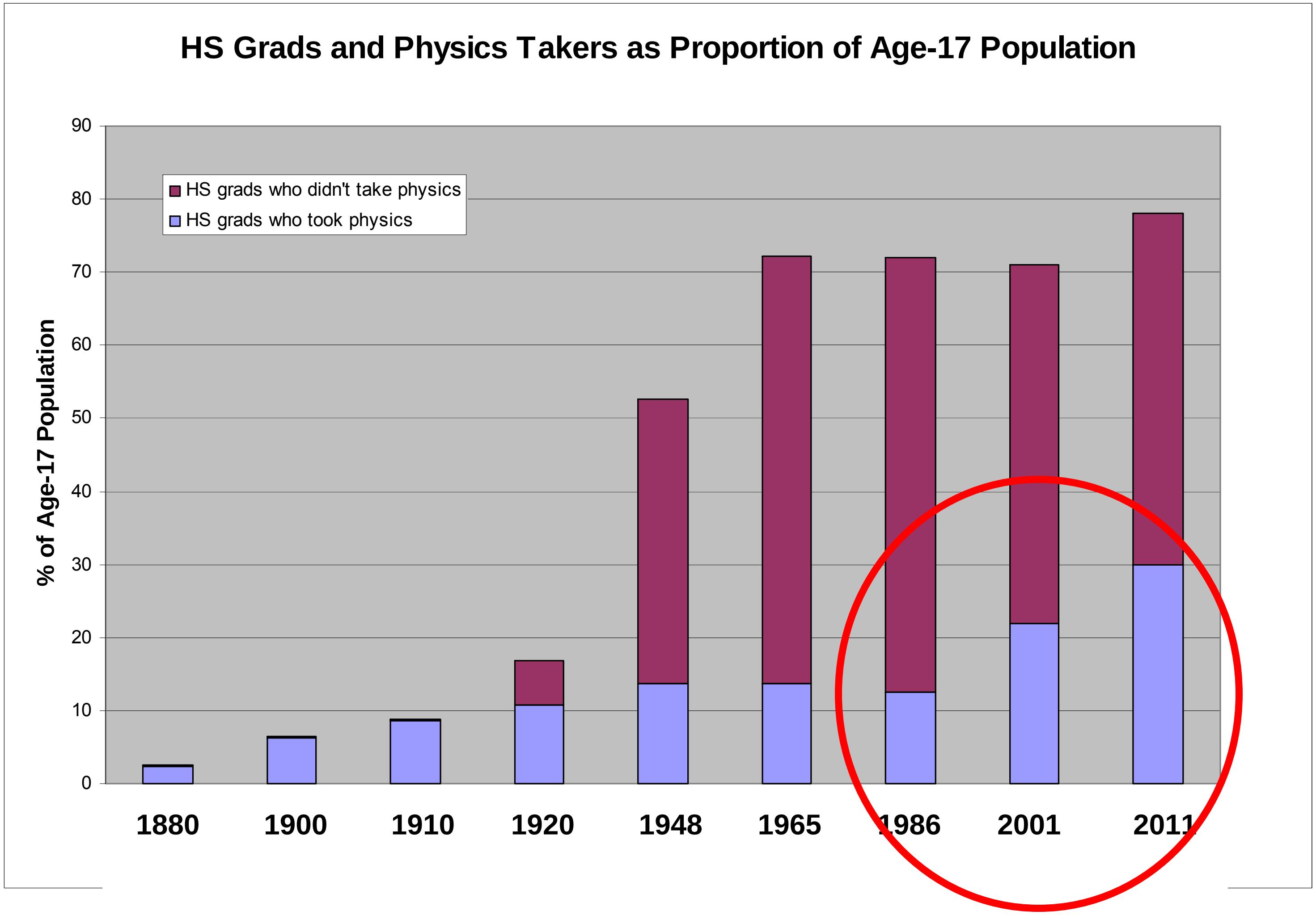
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Recommendations for Teacher Education

- **1909:** Physicists recommend that teacher preparation should be at level of graduate student in physics
- **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)

Recommendations for Teacher Education

- **1960:** AAAS recommends 20-24 semester hours minimum
- **1968:** AAPT/AIP recommend minimum of 24 hours, or 18 hours plus “in-service training”
- **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..”
- **1973:** Physics Survey Committee (NAS) says “successful use of inquiry-directed instruction requires teachers who have themselves learned to investigate in this manner.”

Recommendations by Physics Community for Teacher Education: Summary

- Preparation equivalent to a major or minor in physics (20-24 semester hours, minimum)
- Experience in, and ability to teach physics as hands-on, inductive “inquiry-based’ course

Attempts to Implement Recommendations

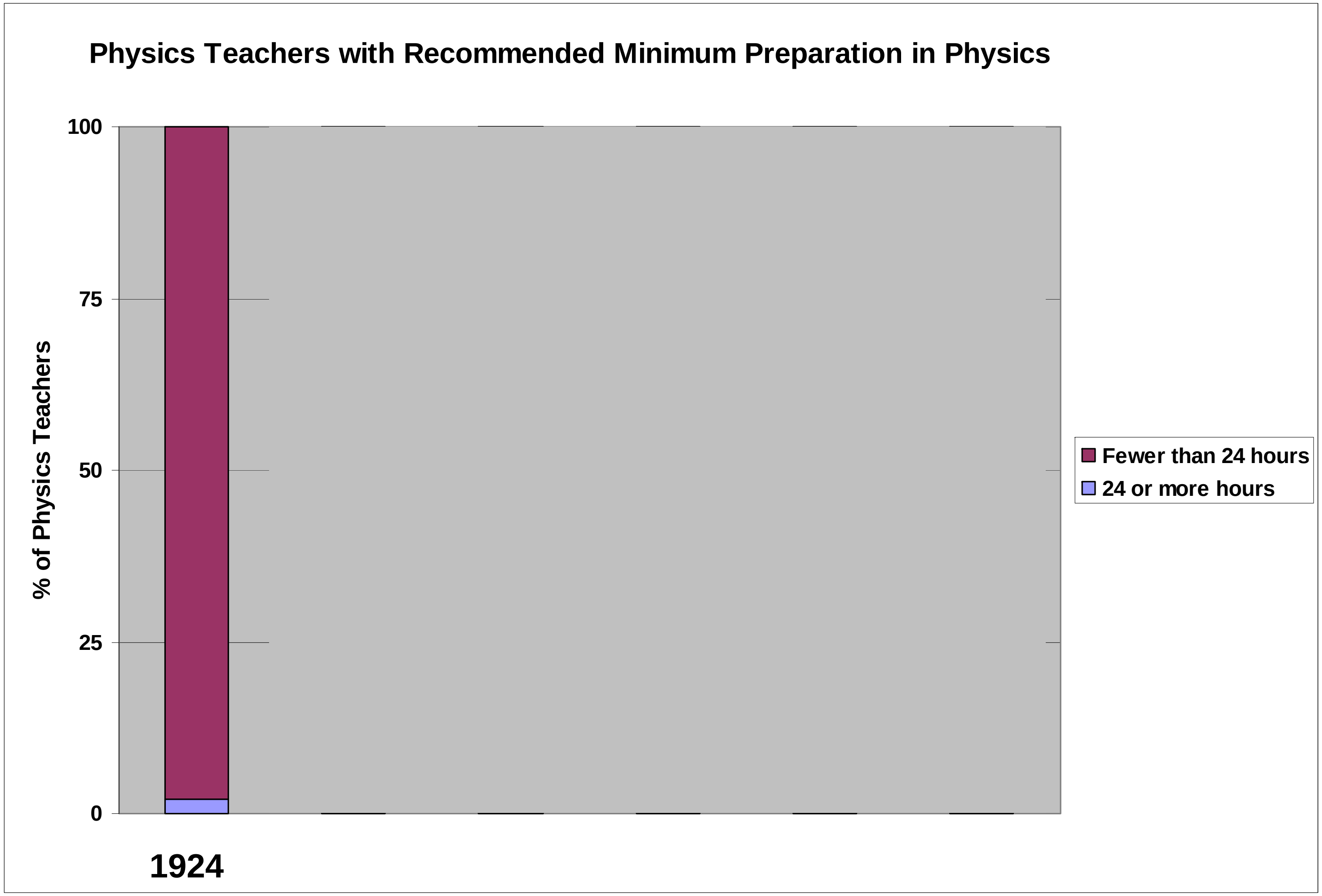
- **1939:** AAPT forms “Committee on the Teaching of Physics in Secondary Schools.”
- **1946:** AAPT reports on “deficiency in the number of well-trained science teachers.”
- **1947:** First summer institute for in-service physics teachers, sponsored by GE, to remedy deficient preparation.
- **1955:** 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.

Attempts to Implement Recommendations

- **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

Outcome: 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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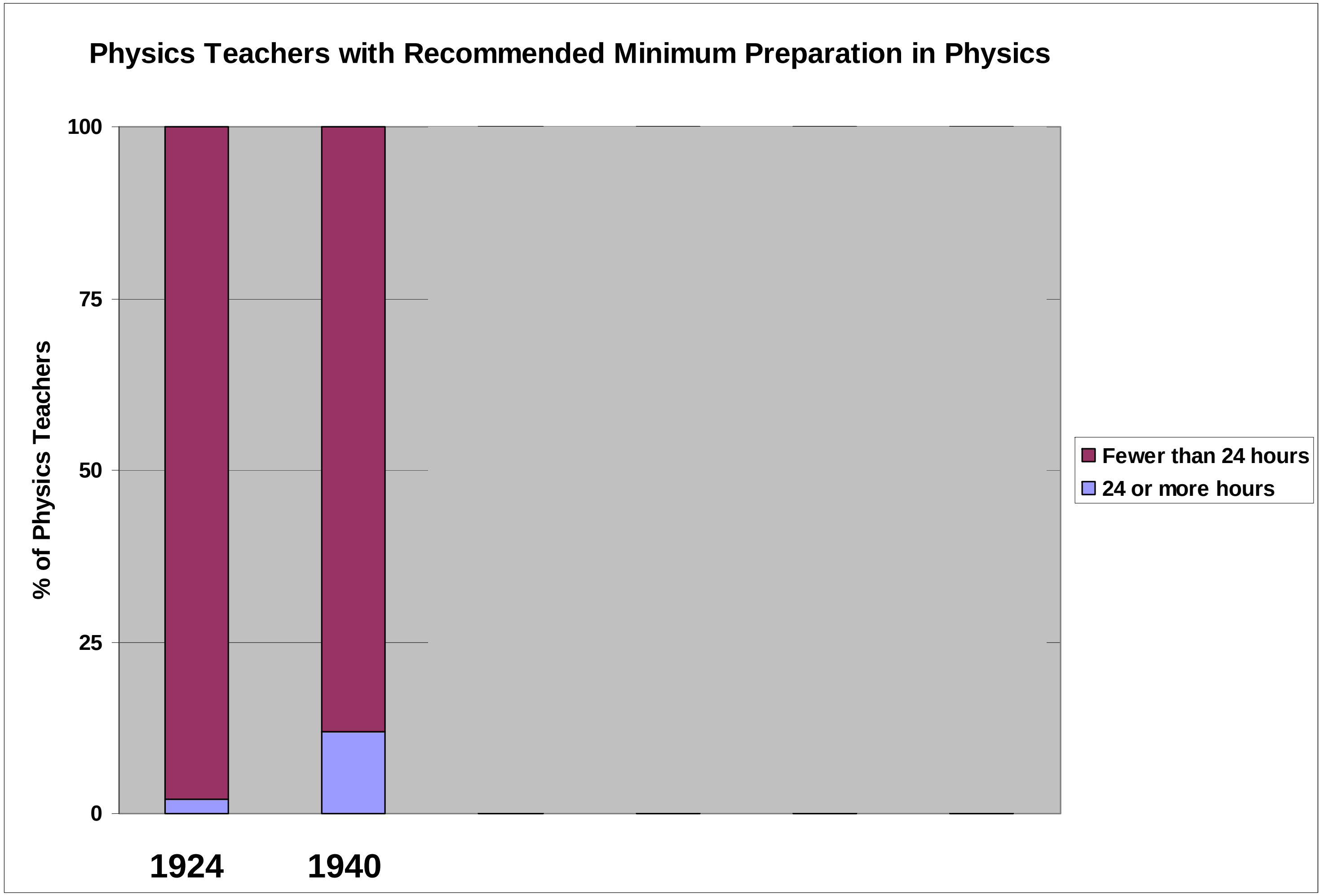

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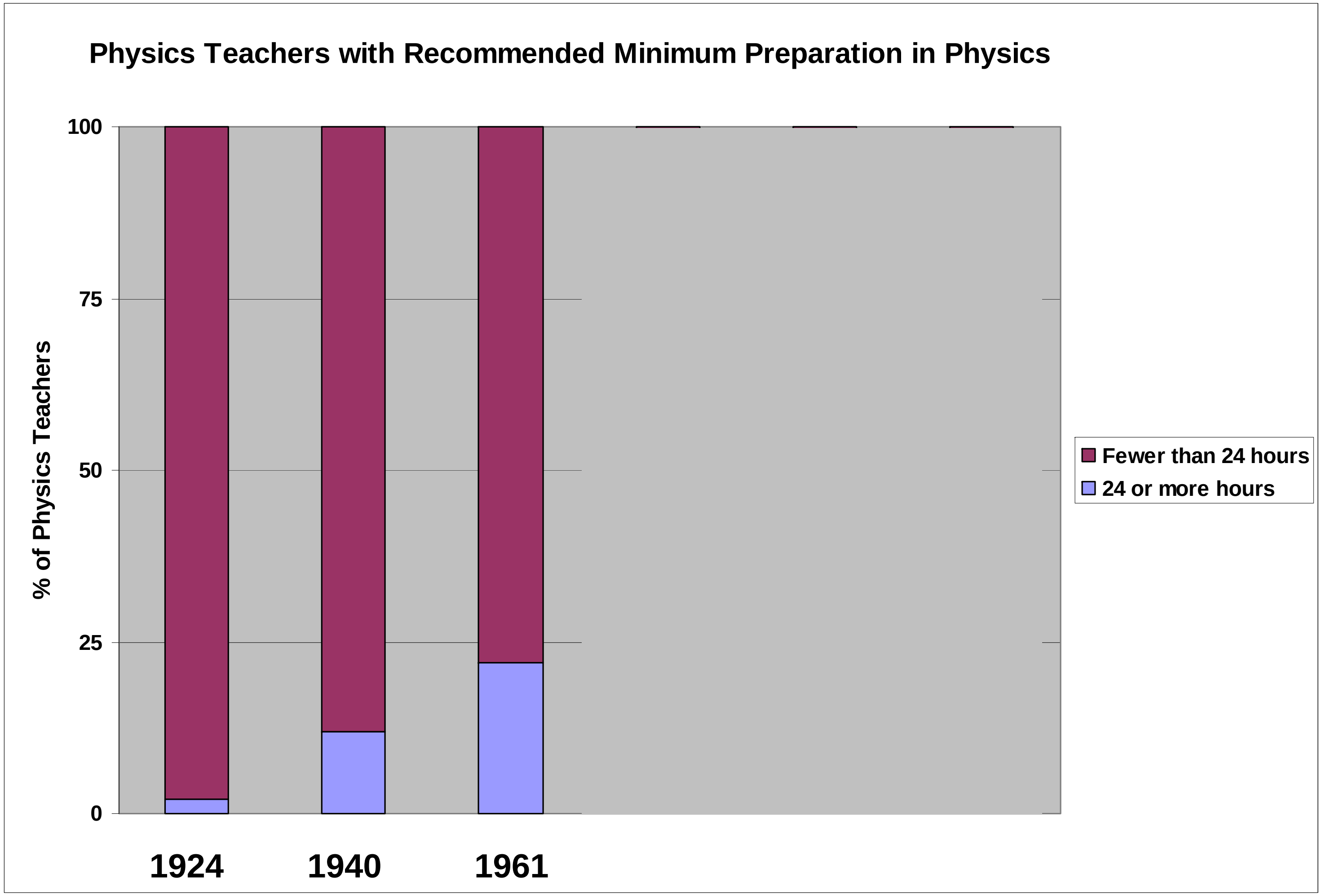

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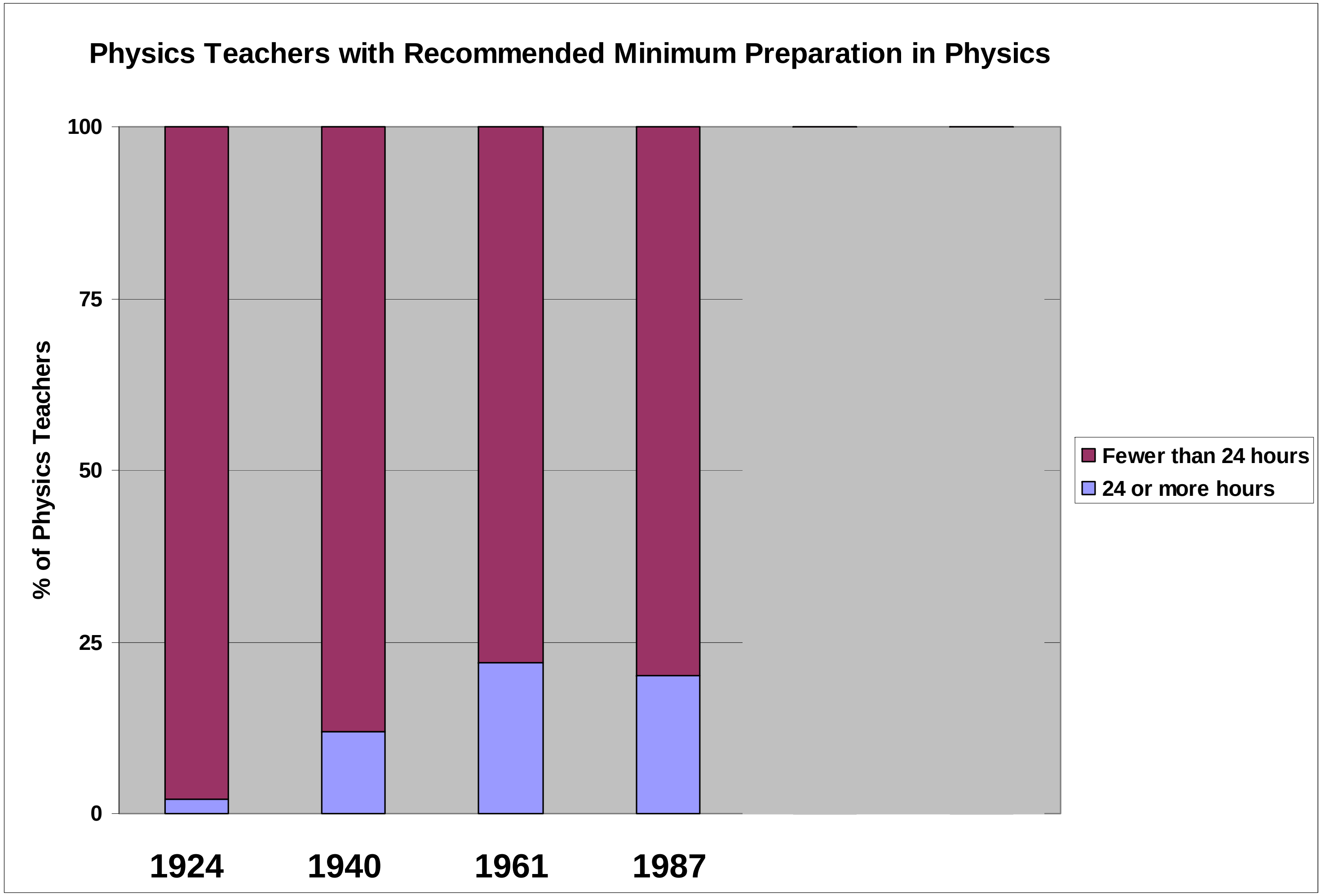

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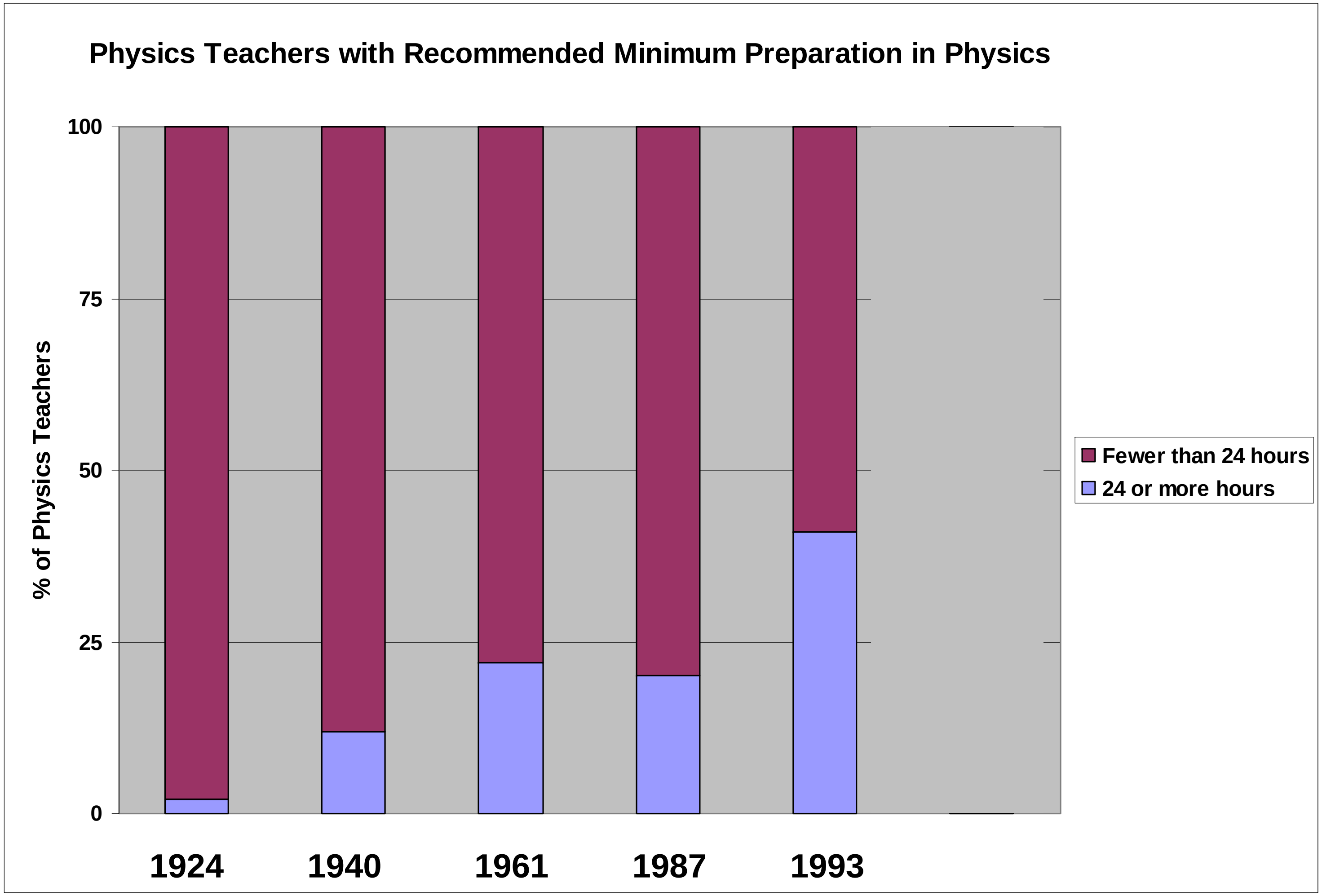

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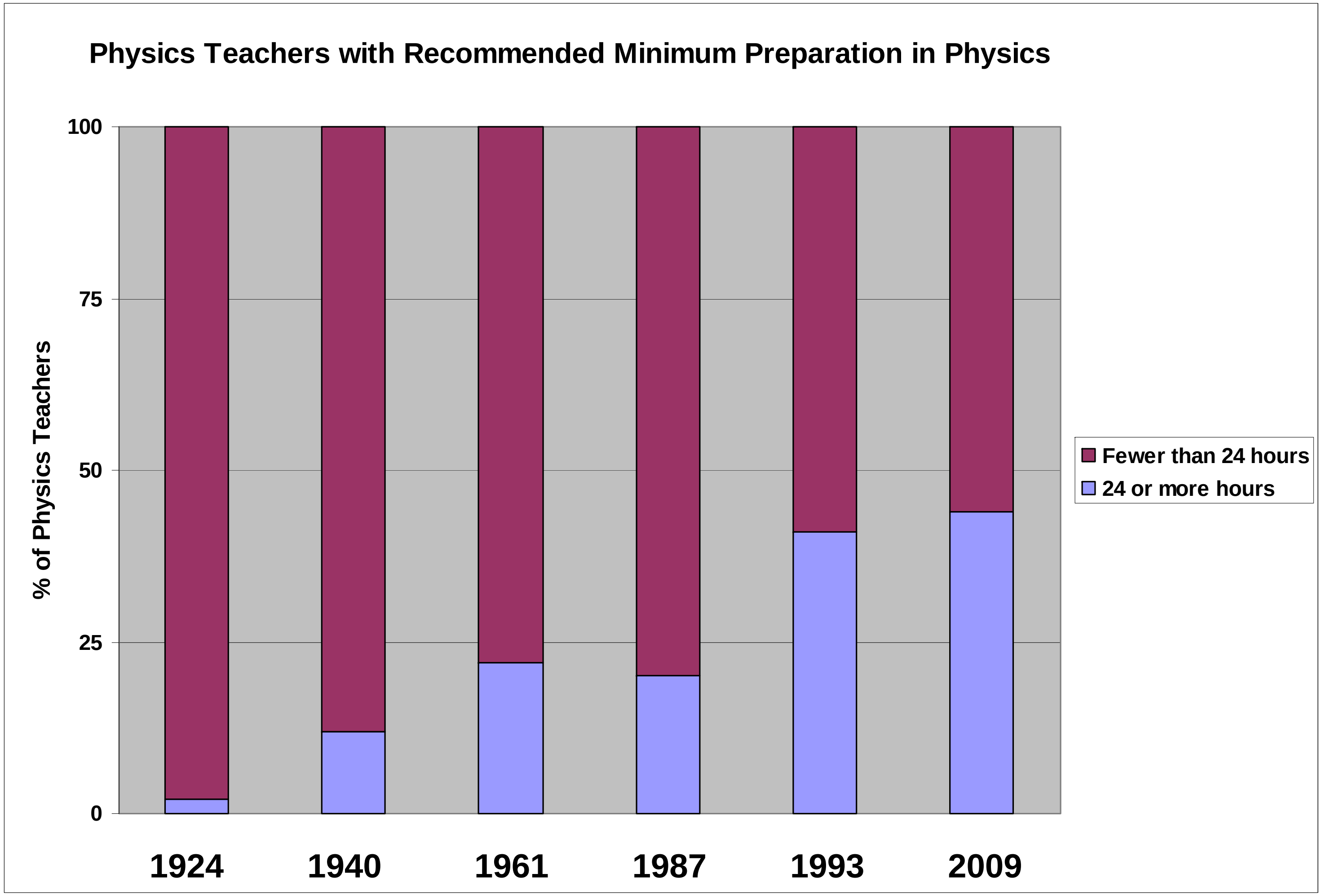

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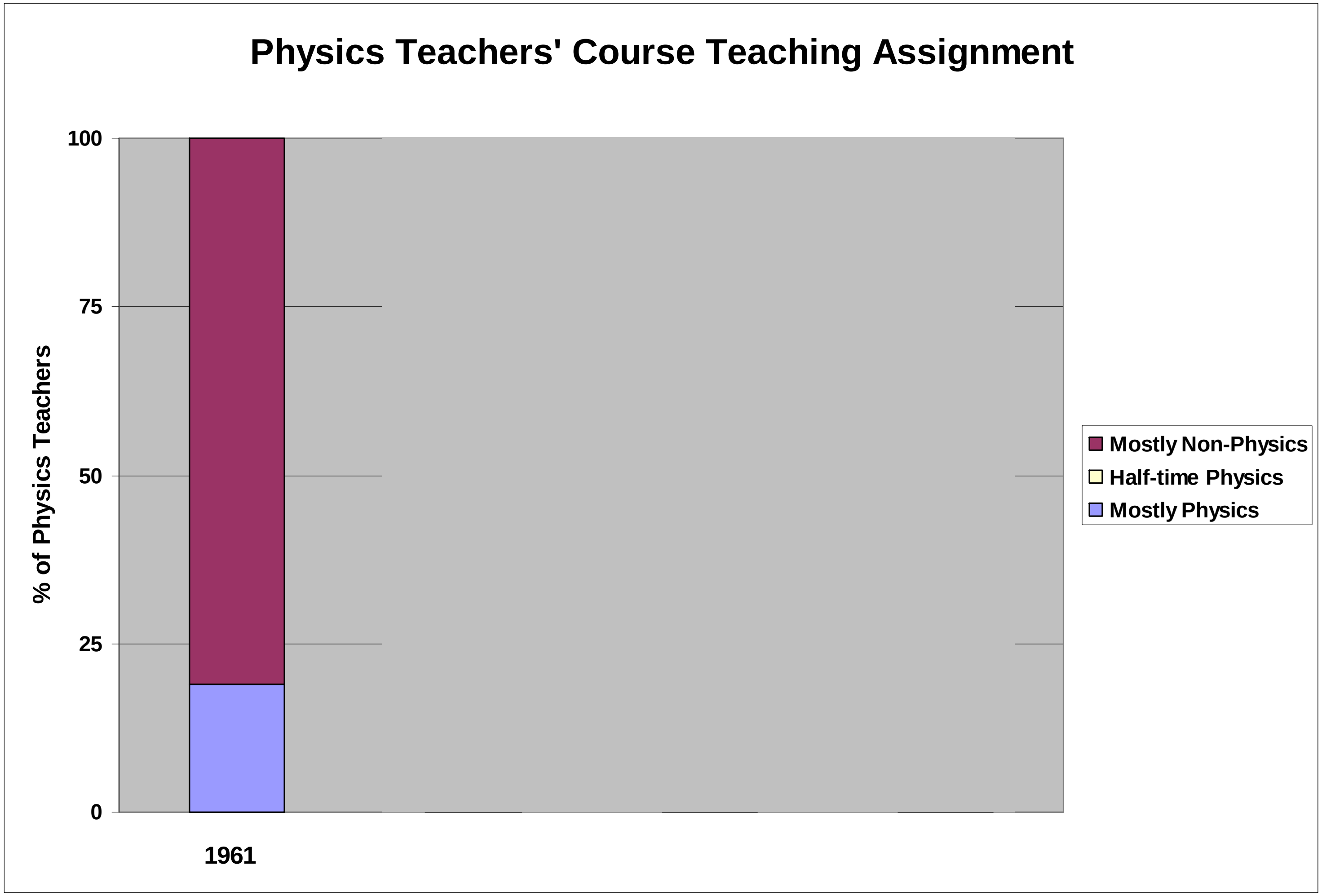
Physics Teachers Spend Most of Their Time Teaching Other Subjects

- 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*.



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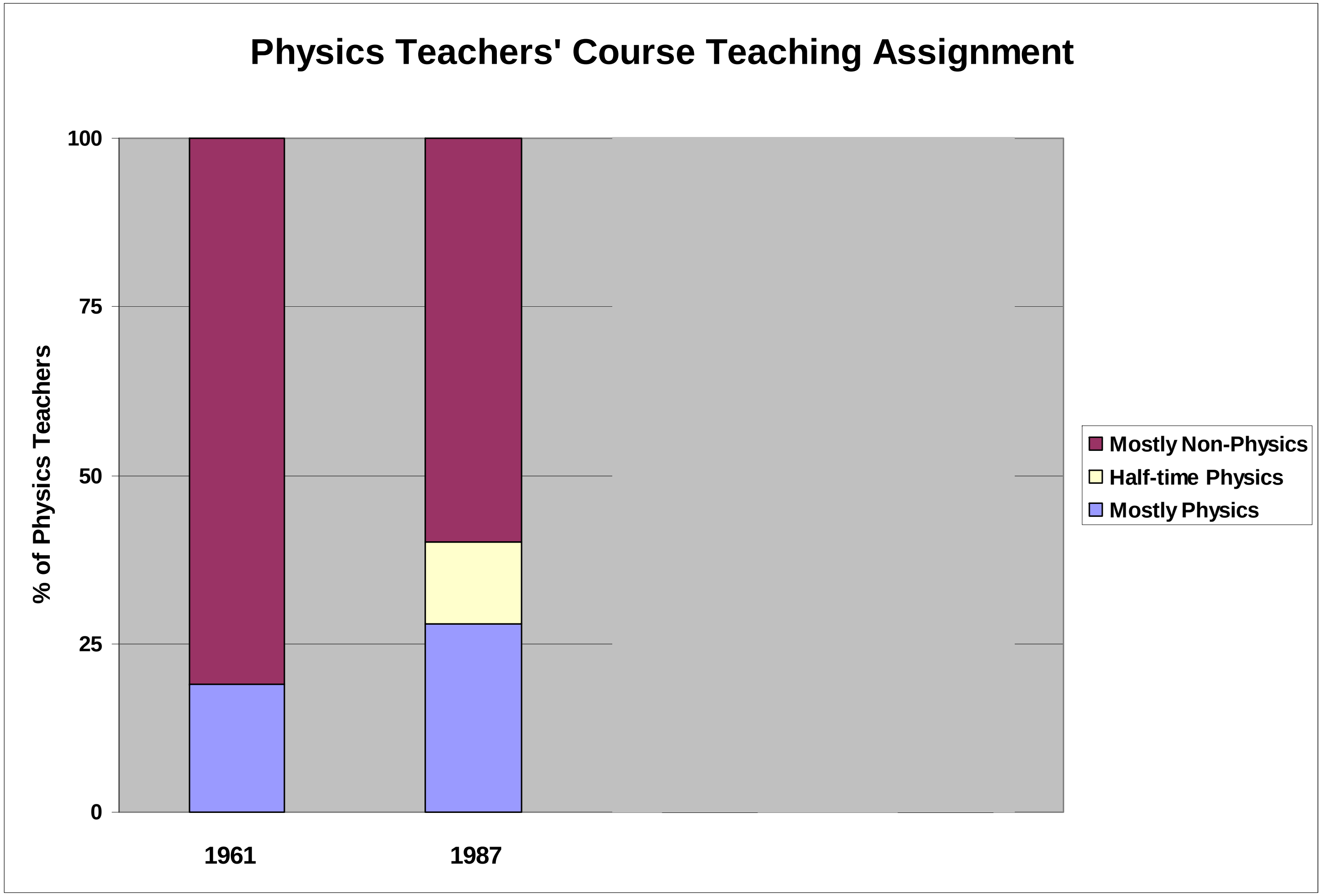

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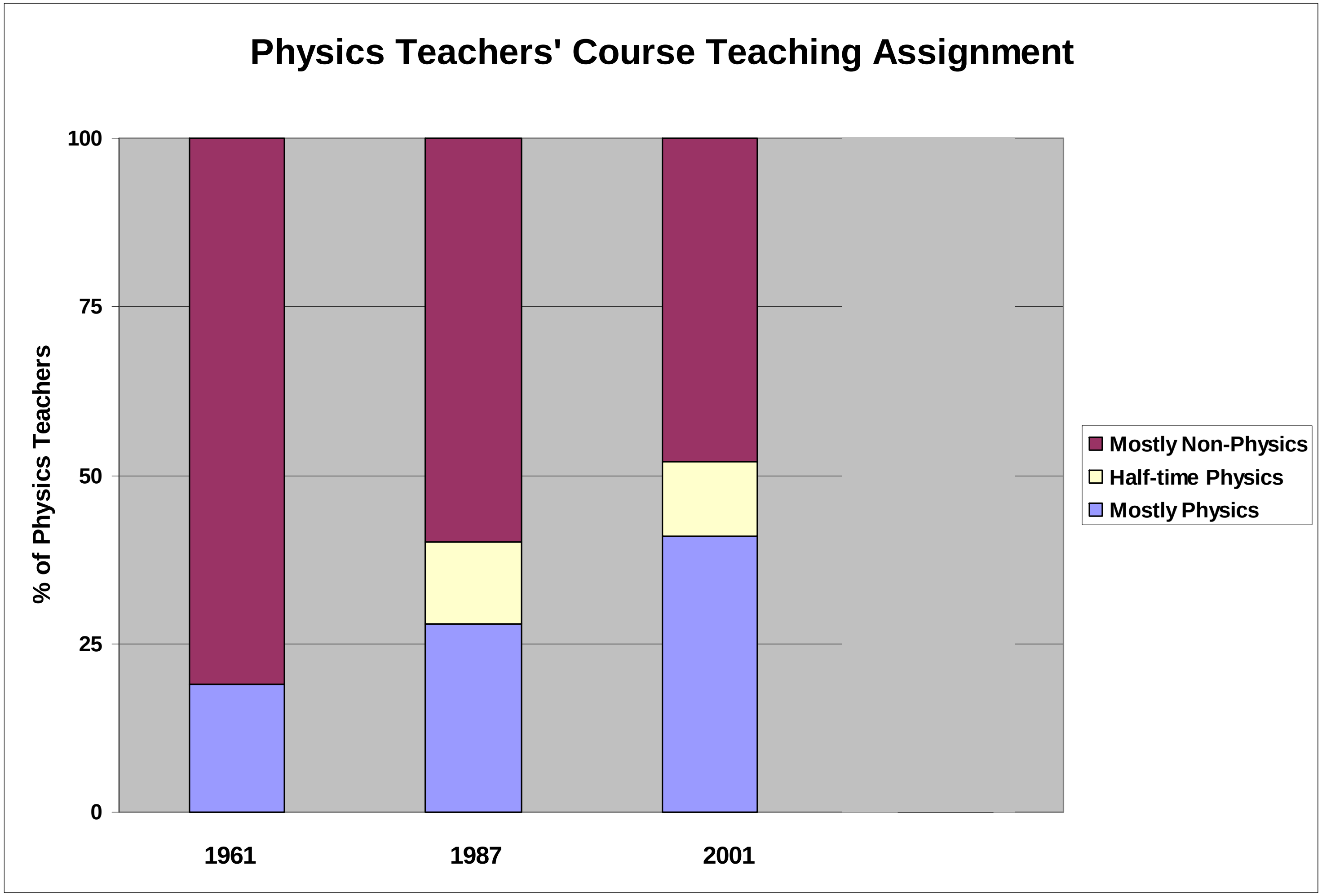

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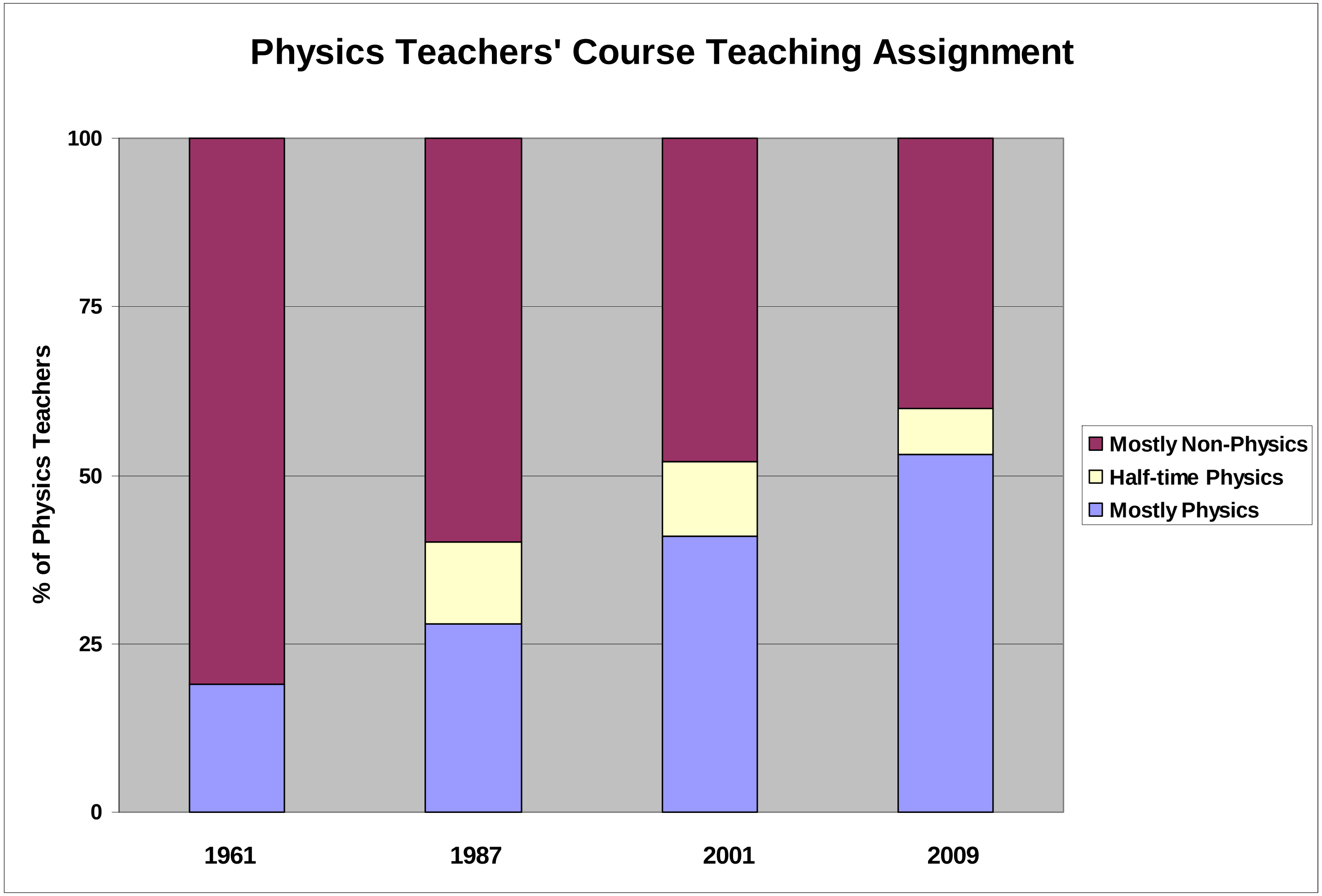

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Courses for Physics Teachers

- Many teachers’ colleges, state colleges, and universities offered courses on physics pedagogy

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, 3 sections, ASSOCIATE PROFESSORS MILLIKAN AND MR. HAM; Winter Quarter, 2 sections, ASSOCIATE PROFESSORS MANN AND MILLIKAN; 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.

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

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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.

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.

Courses for Physics Teachers

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

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- **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:

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

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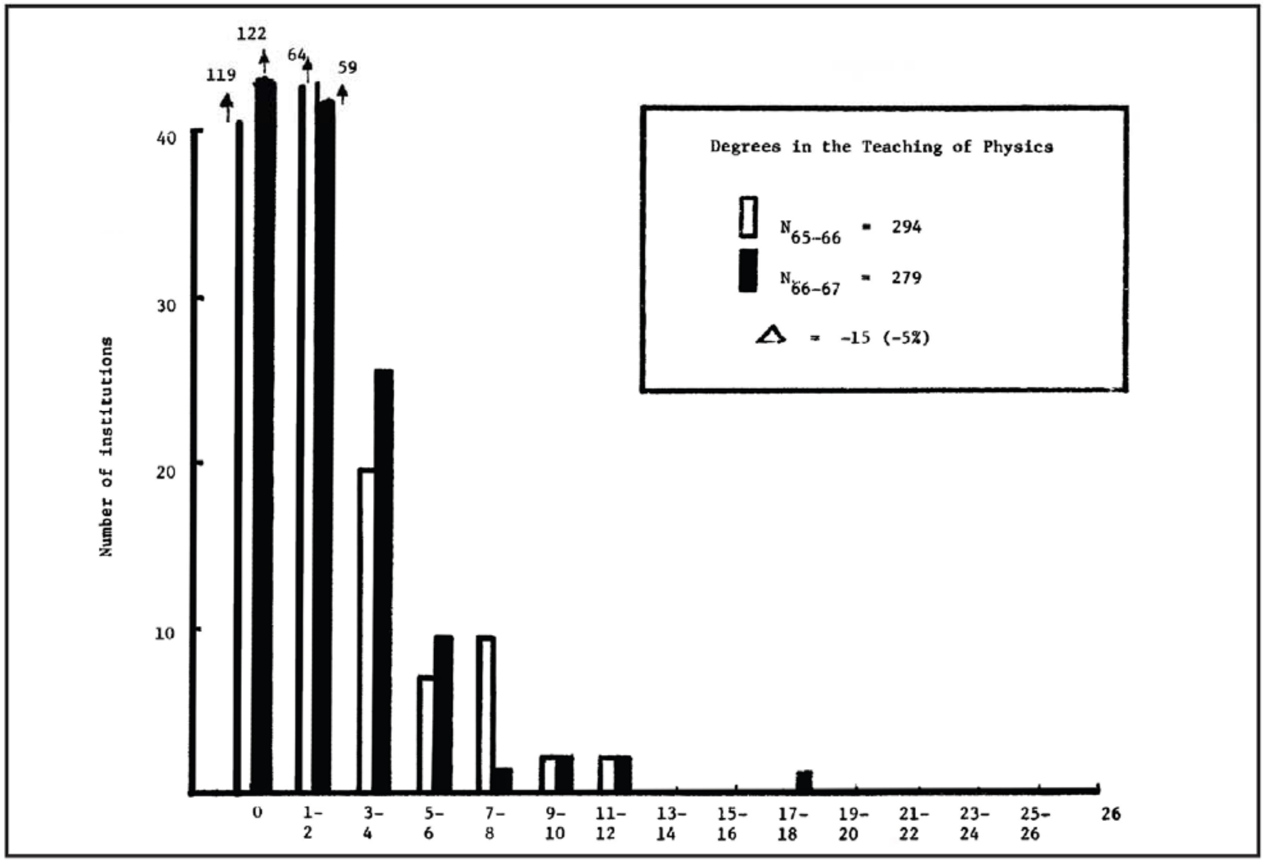
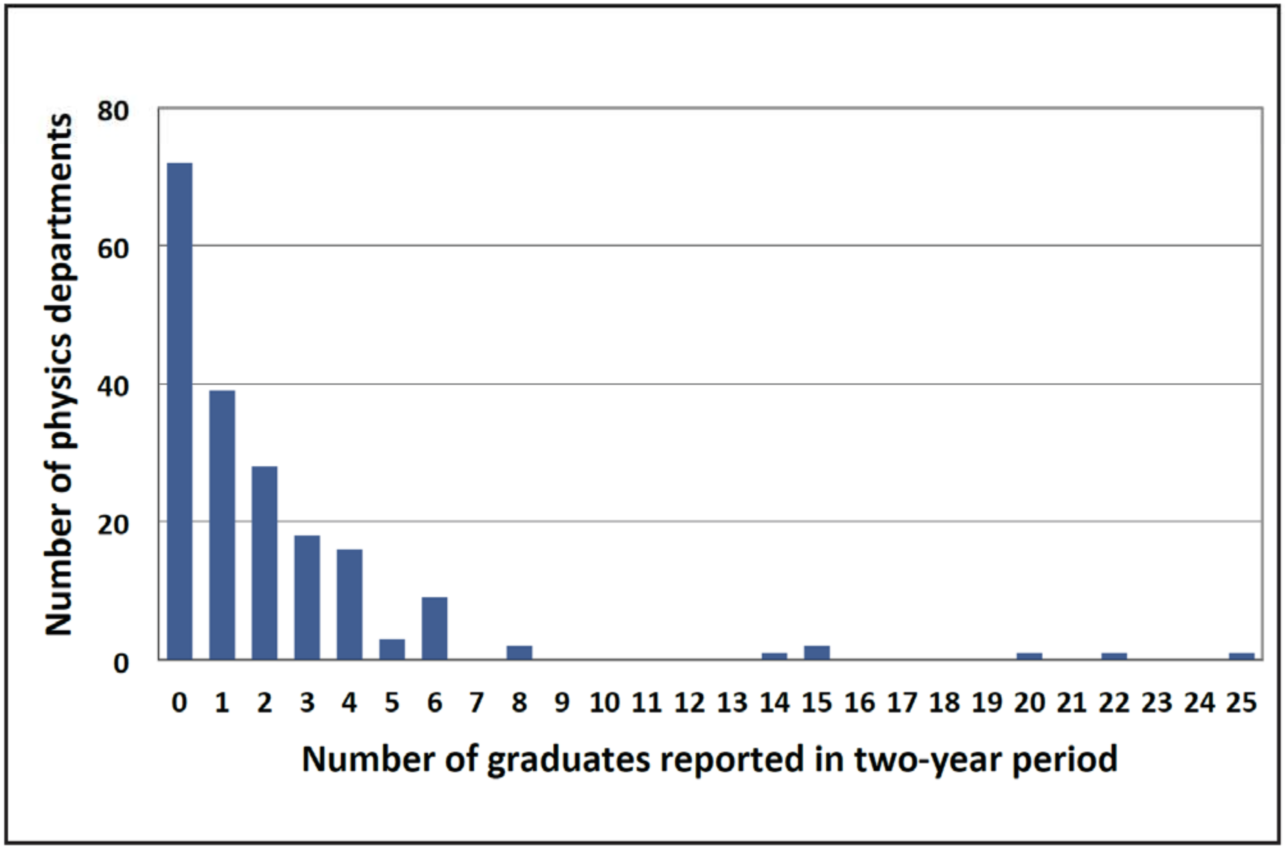
- **2013:** "…the physics community is not producing enough highly qualified physics teachers to meet the growing need at the high school level." *[National Research Council of the National Academies]*

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



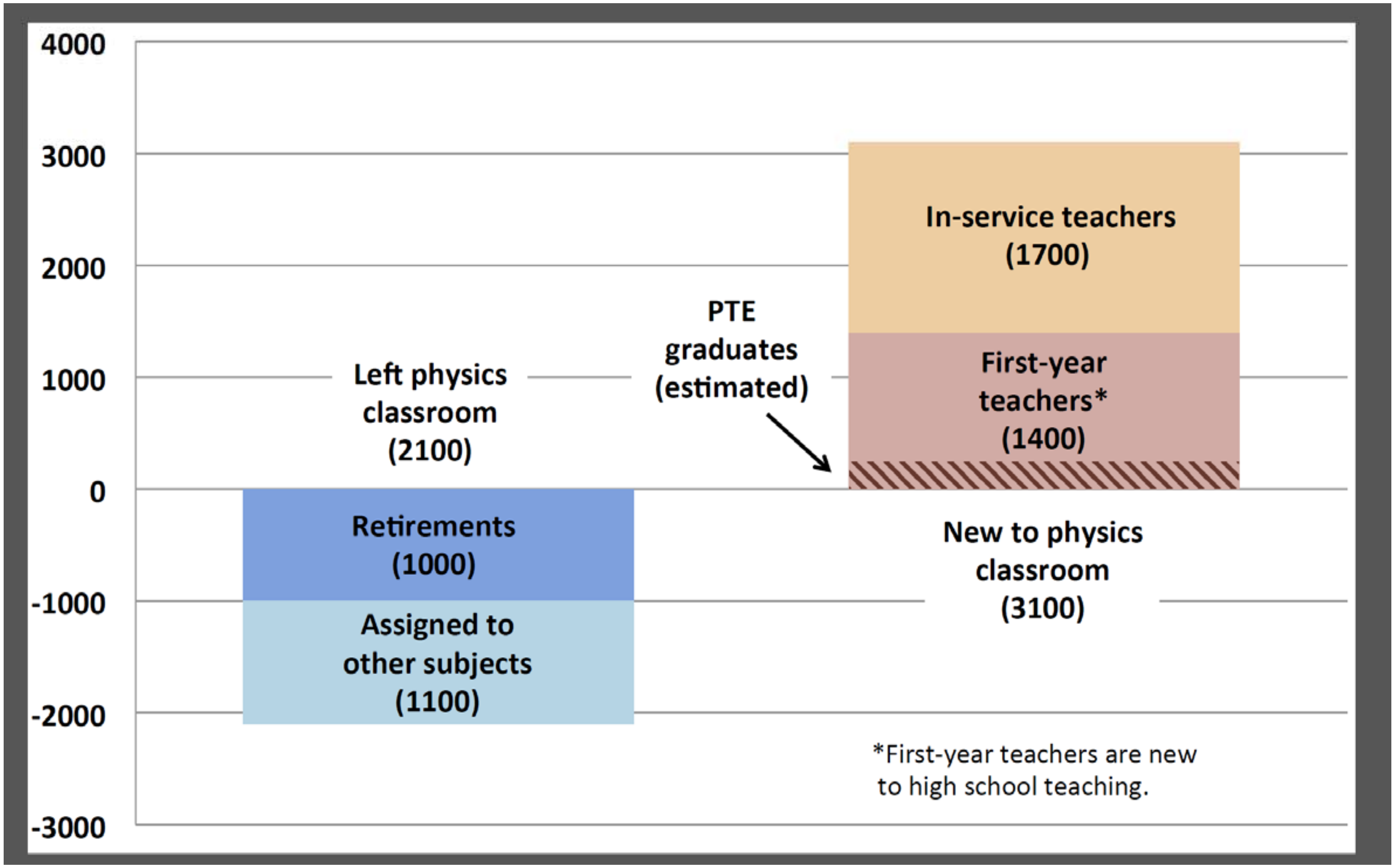
Newton and Watson, *Research on Science Education Survey* (1968), p. 26

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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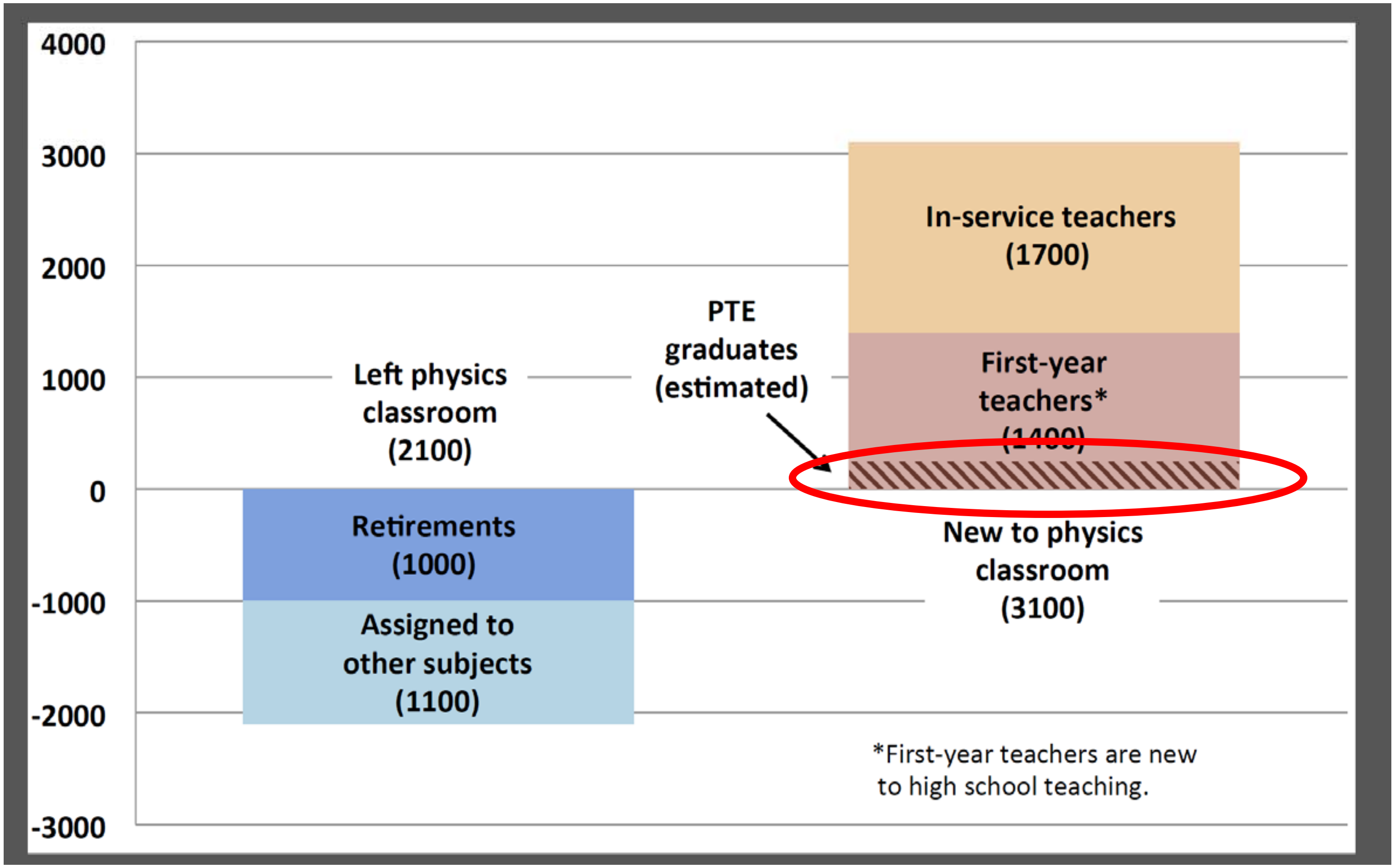
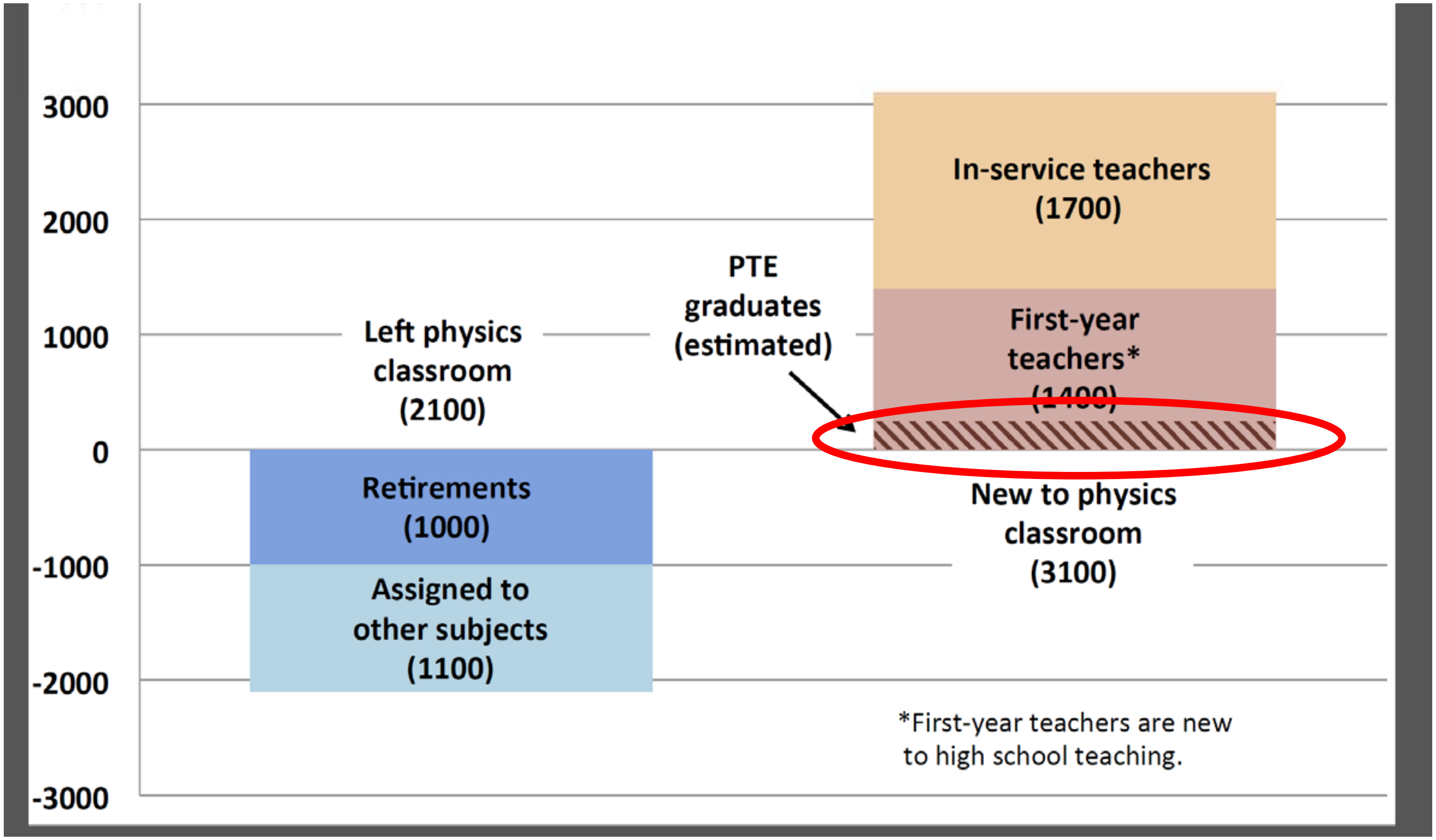


Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* (2012), p. 17

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

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]

Summary

- Lack of an integrated, multi-year physics sequence makes it virtually impossible to match high levels of achievement observed in many other countries.
- 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.
- Preparation is demanding and time-consuming; most physics teachers did not prepare or expect to teach physics.
- Lack of supply plus lack of *real* demand for well-prepared physics teachers, and only a single-year course, makes major reform of high school physics extremely challenging.