AAPT PHYSICS EDUCATION
AMERICAN JOURNAL of PHYSICS

Transforming the preparation of physics teachers

David E. Meltzer and Valerie K. Otero

Citation: American Journal of Physics **82**, 633 (2014); doi: 10.1119/1.4868023
View online: http://dx.doi.org/10.1119/1.4868023
View Table of Contents: http://scitation.aip.org/content/aapt/journal/ajp/82/7?ver=pdfcov
Published by the American Association of Physics Teachers

GUEST EDITORIAL

Transforming the preparation of physics teachers

I. INTRODUCTION

The teaching of physics in U.S. high schools has always had a deeply paradoxical nature. On the one hand, for more than a century physics (together with biology and chemistry) has been widely accepted as a foundation of high school science education and enormous amounts of resources have been expended to ensure that courses be widely available. At the same time, a commensurate expenditure of resources for the education of teachers for those same courses has never taken place: most high school physics courses are now—and have always been—taught by teachers who were never specifically prepared for that job, and who have not had the requisite preparation recommended by physics educators (that is, a major or minor in physics).[1] Many well-qualified and highly committed teachers do exist, of course, but a majority of U.S. physics students are not fortunate enough to have one. Why, one might ask, has there always been a proliferation of courses taught by those considered inadequately prepared to teach them?

Since the 1890s, there has been a broad consensus that laboratory-based physics instruction in high school serves (or can serve) a variety of important goals, including preparation for college study and the development of scientific knowledge and reasoning skills useful for modern technological society.[2] High school physics courses could help enable citizens to make well-informed decisions affecting the nation's well being, while strengthening the technical skills of the workforce.[3] Some have asserted that for the sake of their own profession, physicists *in particular* have a special interest in promoting high quality pre-college physics instruction.[4]

In support of these goals, government, business, and academic institutions have published hundreds of reports over the past century recommending the strengthening of high school science education, including a strong focus on physics.[5] A recurring theme of these reports is the need for students to engage in scientific inquiry; that is, a model of scientific investigation in which students deal with genuine questions regarding the behavior of real physical systems, devise and perform experiments to address those questions, and analyze the outcomes to arrive at defensible answers.[6] However, there has never existed a sufficient supply of highly trained, professional teachers with the background and education needed to guide these sorts of investigations. Moreover, it is questionable whether even those teachers who *are* well prepared are being provided with the time and resources needed for effective guidance of their students.

The U.S. science education system originated in the 1800s and long ago institutionalized a course structure that allows too little time to cover too much material.[7] The outcomes have, inevitably, always fallen far short of the hopes and expectations of physics educators.[8] Instructors are forced to try to teach, during a single academic year, a curriculum that in many other nations is spread over multiple years with repeated exposure to fundamental concepts. Standardized learning assessments often emphasize superficial skills, instead of in-depth conceptual understanding. Furthermore, while many research-validated physics instructional materials are now available at the college level, only a handful are available for high schools and those few are infrequently used.[9] We acknowledge these limitations; they reflect the fact that inadequate teacher preparation is not the only obstacle to improving the science education system. Nonetheless, the fact remains that well-prepared teachers are indispensable to any future plans to improve pre-college physics education in the U.S.

The physics community has long held that "the shortage of qualified high school physics teachers is one of the most pressing problems facing American physics."[10] In the 1950s and 1960s, enormous efforts were made and vast funds expended to provide supplemental training and education for practicing ("in-service") high school physics teachers. In recent years, leaders of the physics education community have been outspoken about the need to improve the education of physics teachers, and several have published research-based approaches for addressing the problem.[11] In this Guest Editorial, we propose explanations for the current unsatisfactory state of affairs, explain why we think it is in the self-interest of the physics community to work to change it, and provide recommendations for such change.

II. THE BROADER IMPACTS OF HIGH SCHOOL PHYSICS INSTRUCTION

University physics instructors in the U.S. often find it practical to assume that students who both did and did not take high school physics may be treated as equivalent to a first approximation.[12] Most U.S. students begin college with only limited preparation in physics, or none at all, contrasting strongly with students who have been educated in many other nations' school systems.[13] Limited preparation may have a negative impact on students' ability to complete an introductory course successfully. It may have a similar—and potentially more damaging—effect on students' belief in their own abilities to be successful in science more generally, and on their feelings about physics as a field of study.[14] Although it is often assumed that many students are simply not able to handle a college physics course, this assumption overlooks the potentially significant impact of strong pre-college preparation in physics on performance and retention.[15] To be sure, research indicates that instructional methods and materials used in college courses can have substantial impacts on course outcomes, and the separate effects of high school preparation have not been carefully studied. However, international comparisons of physics performance suggest that pre-college preparation can also be a significant factor. It is also worth noting that most students make a decision to major in physics before leaving high school, and the nature of their high school physics course may well impact this decision.[16]

III. BACKGROUND NEEDED FOR HIGH SCHOOL PHYSICS TEACHING

A teacher without a strong background in physics is not well prepared to begin a career as a physics teacher—one cannot effectively teach what one does not understand thoroughly. Moreover, to teach physics as a process of scientific inquiry, far more preparation is required than mere expertise with textbook problems. Teachers must be comfortable in guiding students to design and troubleshoot appropriate experiments, to collect data relevant to a question about a physical system, to analyze those data using a variety of methods, and—based on this analysis—to make inferences leading to useful models of the system.[17] This inductive reasoning process is a critical aspect of physics, without which a student cannot be said to be truly literate in the field. Guiding students to engage in complex chains of reasoning based on physical evidence is among the most challenging tasks any teacher can face, and it is particularly relevant for physics teachers.

The skills necessary for establishing a classroom environment that supports inductive reasoning require a deep understanding of the practice as well as the content of a field, and this takes time to develop.[18] In addition, while expertise with physics content and process is necessary for effective teaching, it is by no means sufficient. Teachers must be able to arouse a sense of curiosity and wonder about the nature and behavior of physical systems so that students will be sufficiently engaged to care about both the questions that are posed and the resolution of those questions. Students also require guidance in utilizing their intuition and creativity to engage with physics questions. Teachers who do not themselves have deep interest, engagement, and experience in investigations in physical science are not likely to do well at either of these tasks.

Teachers also require knowledge of high school students' specific physics ideas, reasoning patterns, and learning behaviors, and need expertise in designing and executing activities that are appropriate to guide and assess these students. Those who lack this knowledge and expertise—for instance, the average college physics professor—are not well situated to teach high school physics. Unfortunately, a majority of U.S. high school physics teachers are also severely underprepared for this task, as has been the case as long as physics has been taught in U.S. high schools. (There are still many small schools in rural areas in which just one or two teachers must teach a variety of science subjects, thus making it particularly challenging to prepare such teachers with the type of expertise we are describing here.) For over 100 years, prominent physicists have regularly spoken out about this problem.[19] And, although a higher proportion of physics teachers today have completed a physics major than was the case 100 years ago, the fundamental problem that most physics teachers have inadequate preparation remains far from resolution.[20]

IV. ACTUAL PREPARATION OF PHYSICS TEACHERS

During the past 25 years, the proportion of high school graduates that have taken physics has risen rather dramatically from less than 20% to nearly 40% of all high school graduates.[21] As a consequence, the absolute number of students being taught physics by inadequately prepared teachers is now greater than ever before. The proportion of physics teachers with a physics (or physics education) major has never risen above 35%, and the proportion of those with a major or a minor has never reached the 50% level.[22] By contrast, physics educators have long recommended that a major in physics (or, minimally, the equivalent of a minor) should be part of the preparation for the job of teaching physics.[23] We acknowledge that many practicing physics teachers who lack a physics major background feel their years of on-the-job experience teaching physics have given them adequate preparation for their job. However, years of experience are indeed *required* to attain requisite levels of physics knowledge, and during the years in which teachers acquire this knowledge, their physics students necessarily lack the benefit of an *already* well-prepared teacher. That is not to imply that mere possession of a bachelor's degree in physics is sufficient evidence of a background well suited for physics teaching.

In fact, to supplement the preparation of physics teachers, additional, special courses of study in physics education have been recommended in one form or another since the 1880s.[24] In reality, the number of programs that offer such courses to undergraduates is minuscule compared to the number that would be required to prepare adequately the 3100 new physics teachers who each year face a high school physics classroom for the first time.[25] In part this is because the typical physics department simply plays no deliberate role in preparing physics majors to teach physics, although thousands of new physics teachers are employed each year through hiring or reassignment.

V. KEY COMPONENTS OF THE PROBLEM

A recently completed five-year study by the Task Force on Teacher Education in Physics (T-TEP) found that the vast majority of new physics teachers planned and were trained primarily to teach subjects other than physics.[26] In fact, they have had little or no specific preparation for the job of teaching physics. In addition to lacking rudimentary preparation such as a physics major or minor or courses specifically designed for future physics teachers, these new teachers, for the most part, have never had physics teaching experiences that were supervised or mentored by expert physics teachers. Their instructors for education courses generally have neither experience in scientific inquiry nor knowledge of physical science that extends beyond an introductory course. Their supervisors for field experiences and student teaching are almost never specialists in physics pedagogy, and may not even have had any physics teaching experience. Instead, these new teachers are left to find their own way through on-the-job training, usually with few or no physics-teacher colleagues at their local school with whom they might discuss or plan curriculum and instruction. These teachers, including those holding physics degrees, are rarely prepared in the practices of scientific induction themselves and therefore rarely have appropriate pedagogical background for establishing such learning environments for their students.[27] To explain *why* such a faulty "system" is tolerated, we expand our view.

Programs involving systematic education of current or future physics teachers are almost always organized by colleges and universities. But the responsibility for teacher education has always been left in the hands of a few individual faculty members who have taken a direct interest in it, located in a handful of college and university physics departments (and an even smaller handful of education colleges).[28]

At the same time, the responsibility for hiring and employing physics teachers lies with a completely different authority: the individual schools and local school districts, with influence by the state departments of education. However, the schools and districts don't themselves have any direct influence on the number or quality of teachers that are actually prepared. There is rarely any communication, let alone joint planning, between those in the physics departments who educate future (or current) physics teachers and those in the schools who employ them. Consequently, any meshing of supply and demand, either in numbers produced or in quality and nature of preparation, is serendipitous if it happens at all.

Education in the U.S. has always been primarily the responsibility of the individual states and, in practical terms, more often that of the individual school districts; decisions as to necessary levels of preparation of physics teachers are made on a state-by-state (or district-by-district) basis. The default condition has always been that levels of acceptable preparation are set—almost universally—below those historically recommended by the physics education community (i.e., a major or minor in physics); in practice, many individual schools and districts find ways to sidestep even those minimal requirements. The practice of assigning non-specialist "generalist" teachers to physics classes is more than a century old; it originated in an era dominated by tiny high schools staffed by three or four faculty members who each taught multiple subjects.[29] At one time it may have been a matter of necessity, but in today's world this practice imperils achievement of the very goals that motivated placing physics in the curriculum in the first place.

On the other side, very few physics faculty or physics departments take any direct interest in the education of physics teachers. With little demand from the employers of physics teachers and little supply or interest from the higher education institutions that are tasked with preparing these teachers, the "well prepared physics teacher" has always been primarily an idealized figure: desired and recommended but, for the most part, neither required nor produced.

In many other nations, the situation is quite different. Physics teachers are required to have extensive specialized preparation, and resources for that preparation are provided on a national or regional basis by governmental and academic authorities. While most U.S. students take only a single physics course, students in many other countries take multiple physics courses at different grade levels during their pre-university education. Thus, specialized physics teachers are seen as necessary, preparation programs for such teachers are considered essential, and physicists are directly involved in the preparation process.[30] In the U.S., by contrast, it is often considered acceptable (and even necessary) to place completely unqualified teachers in the position of teaching physics courses, simply because the school or district administrators cannot justify, in their own minds, the expense required to provide a qualified instructor for a relatively small number of physics students and physics classes. The fact that U.S. physics students' performance outcomes are poor relative to international standards can thus hardly be seen as surprising.

VI. RECOMMENDATIONS

The way forward is not easy and has no simple formula. Most of the nation's nearly 30,000 physics teachers lack preparation in physics equivalent to a major or minor; substantial measures to address this problem will be required for the foreseeable future. With this in mind, a powerful argument has been advanced that physics teacher education efforts require a strong focus on education and training for in-service teachers.[31] We concur with this assessment. However, since T-TEP focused its investigation on education for pre-service (prospective) teachers, we limit ourselves here to recommendations targeted at this particular group.

T-TEP found clear and concrete measures that may be taken to improve the education of pre-service teachers; its report provides explicit, research-based recommendations for a variety of stakeholders, including (among others) physicists, physics departments, higher-education institutions, and physics education researchers. Here we provide excerpts of some of the recommendations most relevant to physics faculty members:[32]

[Recommendation 2.] Physics departments should recognize that they have a responsibility for the professional preparation of pre-service teachers.

> a. Physics faculty should encourage students to consider teaching as a career option and ensure that interested students receive assistance in pursuing this goal…
>
> b. Physics departments should develop a welcoming and encouraging environment that shows respect for the scholarship and practice of teaching. Physics faculty should encourage their best students to consider teaching and should promote teaching as an intellectually challenging endeavor…
>
> d. Physics faculty should build a relationship with the education department faculty who are responsible for science teacher preparation and should assist students interested in teaching physics in contacting them…

[Recommendation 6.] Teaching in physics courses at all levels should be informed by findings published in the physics education research literature.

> University physics instruction as well as K–12 physics instruction should take advantage of the extensive literature on student learning in physics and on research-validated instructional approaches. This will maximize student learning and will optimize the environment for students to consider teaching careers. Just as in scientific endeavors, in which physicists build on prior research, so too should programs to improve teaching be based on evidence of effectiveness and informed by results of research on how students learn physics…

[Recommendation 12.] Physics departments and schools of education should design certification pathways for individuals in various populations to become well-prepared physics teachers: undergraduate students who have not yet chosen a major, undergraduate STEM majors, graduate students in STEM disciplines, STEM teachers who may not yet be prepared to teach physics, and STEM professionals such as engineers, scientists, and laboratory technicians.

> a. Active recruitment of STEM students into physics teaching is necessary to increase the number of physics teachers. The recruiting pool should be broad and include undergraduates as well as graduate students, physics majors as well as other STEM majors who have sufficient physics background or can acquire it…

Recommendation 6 implies that learning outcomes in undergraduate physics courses may be significantly improved through the use of research-validated instructional methods and materials, an outcome that could be particularly important for prospective teachers. Specific recommendations for addressing such issues have been made elsewhere.[33]

In addition to recommendations and supporting data, the T-TEP report highlights specific practices that were found to be particularly useful for recruiting and preparing physics teachers. We hope that those with an interest in physics education—a category that should include most U.S. physicists—will take the time to review at least some parts of this report, and to consider ways in which they might contribute towards addressing one of the most long-standing problems in U.S. physics.

David E. Meltzer
Mary Lou Fulton Teachers College
Arizona State University
Mesa, AZ 85212

Valerie K. Otero
School of Education
University of Colorado
Boulder, CO 80309

[Otero is a member of the Task Force on Teacher Education in Physics (T-TEP), and Meltzer is Senior Consultant to the Task Force.]

ACKNOWLEDGMENTS

The authors are grateful to Monica Plisch, Stamatis Vokos, Susan Nicholson-Dykstra, Ben Van Dusen, and Steve Iona for valuable comments on earlier versions of this paper, and to an anonymous reviewer who provided several helpful suggestions.

[1]*Transforming the Preparation of Physics Teachers: A Call to Action. A Report by the Task Force on Teacher Education in Physics (T-TEP)*, edited by D. E. Meltzer, M. Plisch, and S. Vokos (American Physical Society, College Park, MD, 2012), available at: http://www.ptec.org/webdocs/taskforce.cfm.

[2]In 1893, the "Committee of Ten" recommended that physics be one of the core courses in the high school curriculum; see National Educational Association, *Report of the Committee on Secondary School Studies* (Government Printing Office, Washington, D.C., 1893), pp. 25–27 and pp. 117–137.

[3]National Research Council, *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education* (National Academies Press, Washington, D.C., 2013), pp. 8–22.

[4]Physics Survey Committee, National Research Council, *Physics in Perspective*, Vol. I (National Academy of Sciences, Washington, D.C., 1972), pp. 733–736.

[5]Some of these reports are enumerated in "Resources for the education of physics teachers," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 83–123 [Ref. 1].

[6]For similar views separated by 13 decades, see: C. K. Wead, *Aims and Methods of the Teaching of Physics* (Government Printing Office, Washington, 1884), pp. 117–122; and National Research Council, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academies Press, Washington, D.C., 2012), pp. 59–63.

[7]See, e.g., R. A. Millikan, "Science in the secondary schools," School Sci. Math. **17**, 379–387 (1917).

[8]A researcher long ago remarked that "what the teacher thinks he is teaching is usually many times what he actually teaches"; see A. W. Hurd, "Achievements of students in physics," Science Education [formerly General Science Quarterly] **14**, 437–447 (1930).

[9]M. Neuschatz, M. McFarling, and S. White, *Reaching the Critical Mass: The Twenty Year Surge in High School Physics* (AIP, College Park, MD, 2008), pp. 17–19.

[10]See references cited in D. E. Meltzer, "Foundational Material I: Historical context of U.S. physics teacher education," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, p. 34, et seq. [Ref. 1]. Also see National Research Council, *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education*, pp. 46–49 [Ref. 3].

[11]See, for example, L. C. McDermott, "Preparing K-12 teachers in physics: Insights from history, experience, and research," Am. J. Phys. **74**, 758–762 (2006), and National Research Council, *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education*, pp. 46–49 [Ref. 3].

[12]Studies suggest that U.S. high school physics students have no greater success in introductory college physics courses than students who instead took high school calculus; see P. M. Sadler and R. H. Tai, "The two high-school pillars supporting college science," Science **317**, 457–458 (2007).

[13]For student preparation, see, e.g., R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," Am. J. Phys. **66**, 64–74 (1998); and D. P. Maloney, T. L. O'Kuma, C. J. Hieggelke, and A. Van Heuvelen, "Surveying students' conceptual knowledge of electricity and magnetism," Am. J. Phys. **69**, S12–S23 (2001). Other studies have revealed very weak performance by U. S. physics students in comparison to students in other nations; e.g., I. V. S. Mullis *et al.*, *Mathematics and Science Achievement in the Final Year of Secondary School: IEA's Third International Mathematics and Science Study (TIMSS)* (Boston College, Chestnut Hill, MA, 1998); and L. Bao *et al.*, "Learning and scientific reasoning," Science **323**, 586–587 (2009).

[14]W. K. Adams *et al.*, "New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey," Phys. Rev ST Phys. Educ. Res. **2**, 010101-14 (2006).

[15]For discussion of physics teacher preparation in other countries, see for example D. E. Meltzer, "Research on the education of physics teachers," in *Physics Teacher Education: Research, Curriculum, and Practice*, edited by D. E. Meltzer and P. S. Shaffer (American Physical Society, College Park, MD, 2011), pp. 3–14 and references therein. For potential impacts of such teacher education, see, e.g., I. V. S. Mullis *et al.*, *Mathematics and Science Achievement in the Final Year of Secondary School*, as well as L. Bao *et al.*, "Learning and scientific reasoning" [Ref. 13].

[16]See, e.g., (a) Harris Interactive, STEM Perceptions: Student and Parent Study (Microsoft/ Harris Interactive, 2011): http://www.microsoft.com/presspass/presskits/citizenship/docs/STEM_Perception_Report.pptx; and (b) W. R. Snelling and R. Boruch, "Factors influencing student choice of college and course of study," J. Chem. Educ. **47**, 326–330 (1970).

[17]NGSS Lead States, *Next Generation Science Standards: For States, By States* (National Academies Press, Washington, D.C., 2013), Volume 2, Appendix F.

[18]G. R. Twiss, "The reorganization of high school science," School Sci. Math. **20**, 1–13 (1920); Physics Survey Committee, National Research Council, *Physics in Perspective*, Vol. I (National Academy of Sciences, Washington, D.C., 1972), pp. 27–30; and S. R. Singer, M. L. Hilton, and H. A. Schweingruber, editors, *America's Lab Report: Investigations in High School Science* (National Academies Press, Washington, D.C., 2006), pp. 138–167.

[19]A recent example is in National Research Council, *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education*, p. 2 [Ref. 3]. For analogous recommendations extending back to 1909, see Meltzer, "Foundational Material I: Historical context of U.S. physics teacher education," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 29–36 [Ref. 1].

[20]S. White and C. L. Tesfaye, *Who Teaches High School Physics? Results from the 2008-2009 Survey of High School Physics Teachers* (AIP, College Park, Maryland, 2010).

[21]W. C. Kelly, "Physics in the public high schools," Phys. Today **8**(3), 12–14 (1955), and S. White and C. L. Tesfaye, *High School Physics Courses & Enrollments: Results from the 2008-2009 Nationwide Survey of High School Physics Teachers* (AIP, College Park, MD, 2010).

[22]S. White and C. L. Tesfaye, *Who Teaches High School Physics?* [Ref. 20]. Earlier studies reveal that the proportions cited here are historic highs; see, e.g., P. W. Hutson, "High school science teachers: A study of their training

in relation to the subjects they are teaching," Educ. Admin. Superv. **9**, 423–438 (1923).

[23] See, e.g., the reports cited in Meltzer, "Foundational Material I: Historical context of U.S. physics teacher education," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 29–36 [Ref. 1].

[24] See reports cited in Section 7 of Ref. 1 (pp. 97–104), "Education and practices of physics teachers."

[25] See Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 16–17 [Ref. 1]. This total is composed of 1400 new high school teachers, in addition to 1700 in-service high school teachers who have been reassigned to teach physics for the first time.

[26] Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 13–21 [Ref. 1].

[27] See, for example, *America's Lab Report: Investigations in High School Science*, edited by S. R. Singer, M. L. Hilton, and H. A. Schweingruber, pp. 147–148 [Ref. 18].

[28] See Ref. 1, and also V. Otero, N. Finkelstein, R. McCray, and S. Pollock, "Who is responsible for preparing science teachers?" Science **313**, 445–446 (2006).

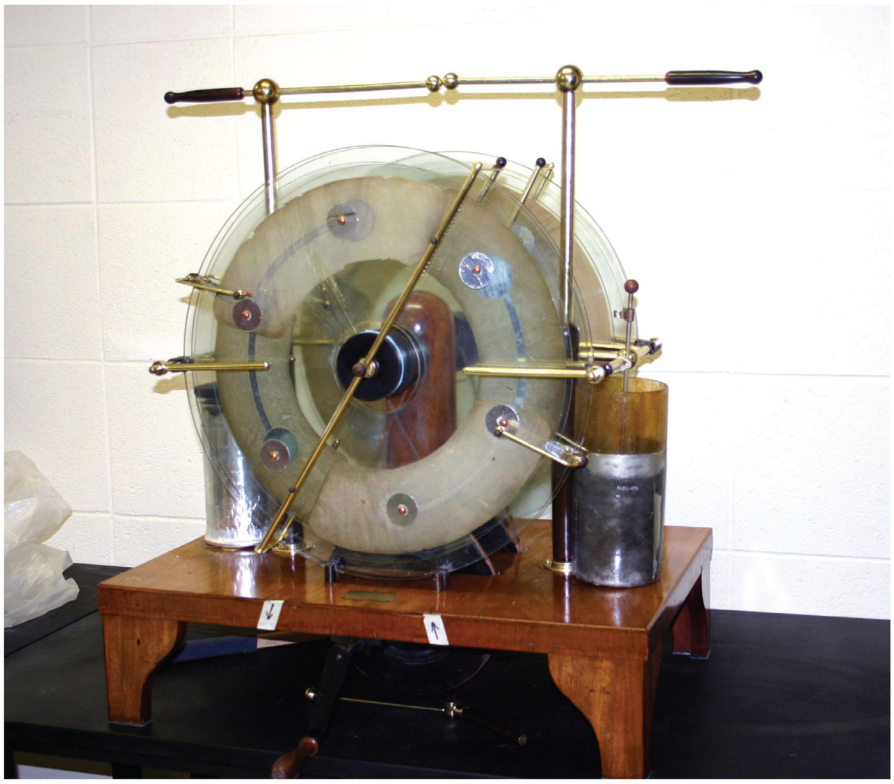
[29] See Meltzer, "Foundational Material I: Historical context of U.S. physics teacher education," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 29–36 [Ref. 1].

[30] See Meltzer, "Foundational Material I: Historical context of U.S. physics teacher preparation," in Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers* [Ref. 1], and Meltzer, "Research on the education of physics teachers," in *Physics Teacher Education: Research, Curriculum, and Practice* [Ref. 15]. For an example, see: B.-S. Eylon and E. Bagno, "Research-design model for professional development of teachers: Designing lessons with physics education research," Phys. Rev. ST Phys. Educ. Res. **2**, 020106-1–14 (2006).

[31] D. Hestenes, C. Megowan-Romanowicz, S. E. Osborn Popp, J. Jackson, and R. J. Culbertson, "A graduate program for high school physics and physical science teachers," Am. J. Phys. **79**, 971–979 (2011).

[32] Meltzer, Plisch, and Vokos, *Transforming the Preparation of Physics Teachers*, pp. 23–27 [Ref. 1].

[33] National Research Council, *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education* [Ref. 3].



Multiple-Disk Toepler-Holtz Electrostatic Machine

From the 1887 catalogue of James W. Queen & Co. of Philadelphia: "New Toepler-Holtz Machine: with four revolving plates, 14 ¼ inches in diameter, mounted on a mahogany base with central mahogany pillar, all elegantly polished. This instrument is of superior workmanship, and the results which can be obtained are very fine … $125.00" There are indeed four plates in this example at Amherst College, but stationary and rotating plates face each other in pairs. It shows signs of having been expertly refurbished in the Amherst machine shop. (Notes and photograph by Thomas B. Greenslade, Jr., Kenyon College)