A Discipline-Specific Approach to the History of U.S. Science Education

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Although much has been said and written about the value of using the history of science in teaching science, relatively little is available to guide educators in the various science disciplines through the educational history of their own discipline. Through a discipline-specific approach to a course on the history of science education in the United States, we have spurred the interest of college science faculty and future high school science teachers as well as doctoral students in discipline-based education research. Our course entails a systematic exploration of past reform efforts in physics education and how they have—or have not—impacted the way physics is taught on a broad scale. In this article, we provide suggestions for those who might want to develop similar courses, particularly in science disciplines other than our own area of physics. We describe methods we used to acquire relevant literature, create appropriate reading lists, and structure and guide classroom discussions and activities. We also provide references to literature in biology, chemistry, and geoscience for scholars who are interested in building their own discipline-specific course.

During the late 1800s, science gained an increasingly important role in the curricula of U.S. high schools and colleges. Ever since then, there have been efforts to transform courses, reform curricula, and make lasting change in how science is taught, both at the college and the high school level. Present-day instructors and discipline-based education researchers can find much to learn in these past efforts, both in their successes and their failures. Through a discipline-specific approach to a course on the history of science education in the United States, we have spurred the interest of college science faculty and future high school science teachers as well as doctoral students in discipline-based education research. The course entails a systematic exploration of past reform efforts and how they have—or have not—impacted the way science is taught on a broad scale. Here, we provide suggestions for those who might want to develop similar courses, particularly in science disciplines other than our own area of physics. We note that there are several valuable publications that provide an overview of the history of science education, most notably the thorough synthesis by DeBoer (1991). However, DeBoer's emphasis is more on broader themes and less on the subject-specific details that are of particular interest to educators in a particular science discipline. Although much has been said and written about the value of using the history of science in teaching science, relatively little is available to guide educators in the various science disciplines through the educational history of their own discipline.

The historical record reveals that discussions by science educators of the 1800s and early 1900s featured many of the same ideas found in today's national reports and debates on science education, as well as in the current literature on science education reform (Meltzer & Otero, 2015). In fact, it is remarkable that many of the present-day themes of emphasis in science education have been so consistently and for such a long time at the center of discussion through the history of science instruction. Specifically, we refer to a focus on activity-based, project-oriented learning founded on scientific induction and an emphasis on deep, conceptual understanding in place of shallow memorization of facts and procedures. These themes were the focus of science educators of the 1880s, 1920s, and 1960s, as well as those of today.

Focusing specifically on the educational history of our own field of physics allowed us to screen thousands of primary source articles in the vast literature on science education, including textbooks and teacher's guides. Along with this filtering, we have used various subject-specific themes for organizing the literature, helping to make these resources accessible and manageable for interested scholars. Our instructors' website archives (in chronological order) much of the physics-specific material and provides annotated reading lists organized by theme (see https://sites.google.com/site/physicseducationhistory/). We also found, but did not examine in detail, historical material in the disciplines of chemistry, biology, and earth science education. At the end of this paper, we provide references to some of this material to serve as a starting point for those who may wish to design similar courses.

In our course, students gain insight into contemporary challenges faced by science educators by exploring the evolution of U.S. physics teaching over the past 150 years, together with the pedagogical issues and debates that accompanied that evolution. The course is based on primary-source literature written by physicists, educators, and administrators of the day, each of whom addressed the quality, process, and content of physics courses or of physics teacher preparation. The topics and issues discussed are highly relevant and appropriate for analysis of science education at the university level, though they tended to focus more on high school instruction. The course materials are appropriate for researchers and instructors engaged in—or planning to be engaged in—science instruction at the introductory level in colleges or in high schools.

The goals of this course are for students (a) to become aware of previous work in science education and of the major efforts to transform science instruction that have taken place in the United States, and (b) to place the national reform movements of today, as well as current discipline-based education research, in the context of past related efforts. These studies are intended to inform the thinking of those who will be designing research projects and novel instructional approaches in present- and future-day science education at the high school and college level. We hope that as a result of taking this course, students will:

- recognize and appreciate the strong similarity between current physics education reform efforts and those that have been made repeatedly during the past 130 years,
- recognize that obstacles to implementation of desired reforms have a long history that reflects powerful and enduring systemic challenges, and
- reframe their current pedagogical efforts and instructional choices within a broader historical perspective to gain insight into potential difficulties and possible pathways for progress.

This course was taught as a doctoral-level, seminar-style course in 2013.

FIGURE 1

Comments from former students 3 years after they took the course.

Current high school physics and math teacher:
Now that I'm back in the HS classroom, I see and feel all of the pressures that make the changes that (the readings) called for so difficult to enact. It's very discouraging. There is so very little leadership on these issues, and some of the greatest obstacles, such as the attitudes of the teachers toward innovation, are very likely a product of poorly managed past "reform efforts." To many seasoned teachers, my effort to lead and transform is just another in a series of "flavors of the week" that will be dropped and replaced by another superficial program in one or two years.

Current assistant professor of physics:
I think the strongest take away message for me from the course was that varying size subsets of people have been talking about the problems inherent in the physics education system for a long time. A lot of the ideas that are (hopefully) gaining traction now have been around for a long time. Which begs the question of why is the current system so hard to change, and what can we learn from the past to help us (today's physics educators) succeed where others have failed.

Current assistant professor of science education:
It is striking how little has changed over the last 100+ years. Many of the calls for reform that we hear today match those from the early 1900s. It was also interesting to see how the movements changed over time (e.g., focusing on lab preparation, understanding common technological devices, and college preparation). It's pretty disheartening to realize how long this has been seen as an issue, but I think overall it clarified my thinking about the purpose of science instruction and strengthened my resolve.

Current assistant professor of physics:
[I learned that] (1) Promoting positive changes on a large scale is very slow work that needs consistent effort. Be ready to be involved for a long time, don't expect change overnight, great ideas take time to scale up and maintain. (2) Be wary of "scare tactics" to promote STEM education. There may be unintended consequences. For instance by continually emphasizing the workforce relevance of STEM, we may be unintentionally devaluing highly useful aspects of liberal arts education.

Current graduate student:
I think the most impactful aspect of the course has been to locate the current pedagogical and ideological agenda for physics (and science) education in historical context. Often we get wrapped up on "our way is the best way," and we fail to recognize that this discussion has been going on for over a century. This struggle makes me realize that progress might depend on some sort of compromise between the conservative and liberal curricular philosophies. It also makes me realize that we are living in an important moment in the history of education, when people who have been traditionally excluded from the conversation about how to best educate ourselves are finally—though timidly—included at the table.

Current graduate student:
I think it is important to recognize that current efforts in physics (and science) education are rooted in, or at least informed by, past curricular and pedagogical efforts. This is not to say that we're just repeating the cycle, but rather that we should be aware of what societal/political/ideological factors seem to drive the sea-change. One example is the parallels between the policy briefs that came after Sputnik, "A Nation at Risk", and PCAST, and how political and economic interests (for the U.S. to remain competitive in the global stage) drive the emphasis of STEM education. Is this the only way our system and, therefore, we could/should make our discipline relevant and desirable?

Six graduate students and three postdoctoral scholars were enrolled. Of the nine students who took the course, one went back to teach high school physics after completing his PhD, four students have gone on to become professors in physics and education departments, two students are now serving as postdoctoral scholars, and one student is currently completing his doctoral degree; we were unable to contact one student.

We did not carry out a formal assessment of course outcomes. However, 3 years after the completion of the course, we administered a survey asking former students whether (and how) the course had impacted their current thinking; some of their responses are shown in Figure 1. The responses suggested that we had made good progress in achieving our course objectives. For example, all of the students who responded to the survey mentioned that they were surprised by how little has changed over the past 100 years and that they learned that change can take a very long time.

Our physics-specific course is divided into 10 chronologically organized segments, each with its own theme, but all focusing on core questions that run throughout (though are not always explicit) in the published literature: (a) Why and how should physics be taught? (b) To whom should physics be taught? and (c) What physics should be taught? Related topics include the role of the laboratory and attempts to make physics "relevant" to everyday life. Each of these issues is studied through readings, reports, discussions, and student presentations. We believe that this course offers a model that may be adapted by educators in other science disciplines, and we will indicate how elements specific to our physics-oriented course might be adapted to courses in other science areas.

The 10 chronological themes that were addressed in our course are listed in Figure 2 (a longer version of this figure is available online at http://www.nsta.org/college/connections.aspx). It is important to note that many of these themes are apparent in other disciplines as well, although at different times and with different nuanced issues. The other sciences share with physics education, for example, upheavals due to conflicts between high schools and colleges in the 1890s, the "reorganization" of science education in the 1920s, and the reform movements of the 1950s and 1960s. However, the individual disciplines have their own particular issues that merit separate investigation. For example, chemical educators since the 1800s have searched for ways to teach students how dynamical phenomena and lawful behavior at the microscopic "particulate" level ultimately explain and account for the infinite variety of chemical phenomena observable in the macroscopic domain. At the same time, biology educators

FIGURE 2

Key issues and important events for each period (for longer version of this figure, visit http://www.nsta.org/college/connections.aspx). PER = physics education research.

A. Origins of physics education in the U.S., 1860–1884
A majority of physics instructors professed support for the "inductive method" of instruction.

B. The move toward laboratory science instruction, 1885–1902
Laboratory physics instruction was institutionalized in most high schools, with a steadily increasing emphasis on mathematical formalism and quantitative experiments.

C. New movement among physics teachers, 1903–1910
Only 40% of students were passing the college entrance exam. Many teachers attributed the "low quality" of high school physics instruction to overemphasis on memorization and rote procedures, and began a "new movement among physics teachers" to reform instruction.

D. Project method, and beginnings of PER, 1911–1914
The project method was seen as a strategy for making physics relevant to "everyday life." This was the final period of intense physicist involvement with high schools until the 1950s.

E. Reorganization of the secondary curriculum, 1915–1922
General science courses were promoted by science teacher educators and treated skeptically by physicists.

F. Dominance by educationists, 1923–1947
Physics of "everyday life" dominated discussions about physics education, and concerns about teacher education were amplified by post–World War II teacher shortages.

G. Reengagement by physicists, rise of curriculum reform, 1948–1966
A rapidly increasing number of university-based "institutes" for physics teacher education were funded by the federal government, together with major new curriculum development projects. This helped to reengage physicists in high school physics curriculum development and physics teacher education.

H. Culmination of postwar reforms and emergence of modern PER, 1967–1991
Physicists initiated studies of student reasoning, problem solving and physics learning. The first U.S. PER faculty positions appeared in university physics departments.

I. Rise of conceptual physics and of modern PER, 1992–2001
There was a dramatic and steady rise of enrollment in high school conceptual physics courses. A broad-based PER community began to develop in university physics departments. National standards in science education were developed, with special attention to science content and inquiry processes.

J. The present day: High school physics, national reports, 2002–2017
The number of PER PhDs increased along with the number of discipline-based education researchers at universities. New science education standards were developed, emphasizing "science practices."

have made a long and gradual transition from a once-exclusive focus on macroscopic treatment of plant and animal structures to the now-dominant emphasis on the microscopic cellular and biochemical basis of living systems. The earth sciences have yet another story to tell, one marked by increasing recognition of large-scale changes in the earth's surface structure. The wealth of historical literature in these other pedagogical disciplines has been touched on (see references), but has yet to be subjected to a systematic and up-to-date investigation.

The relationship between past and present instructional methods in science is particularly complex because science, of all subject areas, has undergone arguably the most dramatic changes during the past century. The present-day teaching of high school biology, to take one example, is so far removed from the approach that dominated 130 years ago as to be nearly unrecognizable as the same course. What commonalities, then, do biology educators of today share with those of the 1880s and what attempts at educational reform have been repeated throughout the history of biology education? Although there have been many changes, some things have remained remarkably consistent in all of the sciences, such as calls for curricular reform and attempts to engage students in authentic scientific practices. An exploration of these types of questions can help science educators identify those aspects of science education that transcend specific time periods and particular epochs of scientific knowledge.

Finding appropriate historical material

Any discipline-specific course will need to draw from a very large number of possible references, each one in turn leading to yet other potentially relevant readings. Here we summarize the approach we used, which may be adapted to other science disciplines. After reviewing only those references specific to physics, we developed the chronological categorization presented in Figure 2. Within each of the 10 segments, a representative sample of recommended readings was selected; the readings are listed on our website (https://sites.google.com/site/physicseducationhistory/). The course materials available at the website and in relevant articles provide a synopsis of each time period, including the key dates, names, and issues. A much more extensive list of selected optional background readings for each period is also provided at the course website.

Process for finding relevant discipline-specific materials

A surprising number of full texts for most older items in the literature, as well as many more recent reports, are readily available online from Google Books (https://books.google.com/advanced_book_search?q), Hathi Trust (http://www.hathitrust.org/), and the Internet Archive (https://archive.org/details/americana); many reports are available from ERIC (http://eric.ed.gov/). A year-by-year search on Google Scholar can turn up many writings by key authors that might otherwise be hard to find. In general, items published in 1922 and earlier are in the public domain, and full texts of those should be available online. To find appropriate historical literature for physics, we searched for and found a few key sources—for example, Mann (1912)—which themselves

FIGURE 3

Suggested references for biology, chemistry, and earth science.

Biology

1. Committee on Educational Policies, Division of Biology and Agriculture. (1957). *Biological education: A partial bibliography*. Washington, DC: National Academy of Sciences–National Research Council.
2. Hurd, P. D. (1961). *Biological education in American secondary schools 1890–1960.* Washington, DC: American Institute of Biological Sciences.
3. Glass, B. (1962). Renascent biology: A report on the AIBS Biological Sciences Curriculum Study. *The School Review, 70*, 16–43.
4. Mayer, W. V. (1986). Biology education in the United States during the twentieth century. *The Quarterly Review of Biology, 61*, 481–507.
5. Rudolph, J. L. (2002). *Scientists in the classroom: The cold war reconstruction of American science education* (pp. 137–164). New York, NY: Palgrave. [Note: This is Chapter 6, "BSCS: Science and Social Progress."]

Chemistry

1. Smith, A., & Hall, E. H. (1902). *The teaching of chemistry and physics in the secondary school*. New York, NY: Longmans, Green.
2. Rosen, S. (1956). The rise of high school chemistry in America (to 1920). *Journal of Chemical Education, 33*, 627–633.
3. Sheppard, K., & Robbins, D. M. (2006). Chemistry, the terminal science? The impact of high school science order on the development of U.S. chemistry education. *Journal of Chemical Education, 83*, 1617–1620.
4. Elliott, M. J., Stewart, K. K., & Lagowski, J. J. (2008). The role of the laboratory in chemistry instruction. *Journal of Chemical Education, 85*, 145–149.

Earth science

1. Matthews, W. H. (1963). Growth of earth science in secondary schools. *School Science and Mathematics, 63*, 637–646.
2. Heller, R. L. (1965). The secondary school earth science course in science education. *Journal of Geological Education, 13*, 71–74.
3. Lewis, E. B. (2008). Content is not enough: A history of secondary earth science teacher preparation with recommendations for today. *Journal of Geoscience Education, 56*, 445–455.

General

Glenn, E. R. (1925). *Bibliography of science teaching in secondary schools*. Washington, DC: U.S. Department of the Interior, Bureau of Education.

provided further references to many other works in physics education. Another excellent starting point is the book by DeBoer (1991), which contains summaries of key historical developments in all the sciences and a wealth of references to the primary literature. Other general sources may be books, review papers, and reports that provide some overview of the field. We offer a few suggested references each for biology, chemistry, and earth science (see Figure 3). These sources and their bibliographies provide names of "main players" along with citations of significant committee reports, journal articles, and textbooks.

To keep to a manageable size an already large collection of course readings, we maintained a very tight focus on physics-specific materials or on physics-specific excerpts from more general reports or conference proceedings. As tempting as it is to delve into the many broader issues in science education, we recommend that discipline-specific investigations maintain a similar tight disciplinary focus. On the other hand, within the physics-specific category, we focused on readings that emphasized broad issues that are of relevance today, in particular on the themes of why and how to teach physics, as well as the 10 subthemes identified in Figure 2. (The notion of what is an "appropriate" theme necessarily evolves as one becomes more familiar with the literature.)

Developing weekly reading lists

To develop reading lists for the course, we suggest organizing the readings into chronological periods, along with attempting to initially identify one "central theme" for each time period—for example, 1885–1902: the move toward laboratory science instruction; 1915–1922, reorganization of secondary curriculum; and 1956–1966, development of "reform" science curricula. All discipline-specific education papers, books, and reports published during a time period may be examined and may then be grouped into major subthemes—for example, teacher education, education research, instructional methods and curriculum development, and textbooks, in accordance with developments in each discipline's history.

It is challenging to cut through the profusion of publications reflecting concerns of the day to identify the principal underlying dynamics that drove (and continue to drive) the inclusion and expansion of scientific disciplines in the school curriculum. Therefore, when selecting and prioritizing readings, we focused on writers who tackled the broader themes head-on (such as C. R. Mann and R. A. Millikan) and avoided spending much time on writers who focused more on relatively ephemeral issues. We further divided thematic units into *required*, *recommended*, and *optional readings* and found it helpful to provide a brief annotation for each required reading. (See sample reading lists at our course website.)

A peculiarity of the science education literature is the enormous and diverse range of laboratory activities and topical emphases—each associated with the technologies dominant at the time—and the incessant and rancorous debates about teaching "science for its own sake" versus "science in everyday life." Specific articles are often dense, complex, and lengthy. It can be challenging for modern readers to understand the context in which specific science topics and laboratory activities are discussed because of the diversity and complexity of the articles and the many out-of-date and unfamiliar experiments. For example, in Hall's (1902) text on physics teaching, a lengthy discussion of an obsolete experiment on deflections of wooden rods under load is the setting for a thoroughly modern example of inquiry-based physics instruction (see pp. 281–283). In cases of lengthy readings, page selections should be provided to direct attention to particularly relevant sections, while still making the full book or article available. In developing the reading list, we tried to omit sections that focused on details of particular experiments and emphasized instead the selection criteria that had been used to decide on which experiments to include.

We note that journals of the past are full of articles by individual science instructors who focus on particular issues and proposed activities for physics, chemistry, biology, and other sciences. However, there are a few authors who explicitly focus on broader themes, many of which resonate today—for example, E. H. Hall and C. R. Mann in physics; A. Smith in chemistry; and in a later era, B. Glass in biology. In developing a reading list in a specific discipline, one might choose to focus on readings by these key individuals as a means for gaining familiarity with the extensive literature base.

Broader themes can be brought to life by examining some of the specific lab activities, textbooks, and exam questions that were used by early science educators; for example, one of the activities in our class was to read portions of actual historical physics textbooks. We asked students to study some of the older texts by picking out a topic that they had recently taught or in which they were particularly interested and to reflect on what insights the text's treatment of that topic offered into the general outlook and approach of the authors. It is useful to see how previous education reformers struggled, as do those of today, with the challenge of incorporating innovative, activity-based assignments within the context of a printed textbook.

Classroom implementation and class discussions

The large number of readings, together with the diverse student population in this course, generated challenges for classroom implementation. We noted some distinctive patterns of student behavior, and in response we adopted certain strategies to try and improve the effectiveness of class discussions. Because of the diversity of issues in the readings of any period, students may tend to linger excessively on a small number of science educators or specific readings, or to focus on the "trees" of particular educational issues in contrast to the "forest" of broad historical trends. We frequently found it desirable to focus on one of the three themes (why and how to teach, to whom to teach, and what physics to teach). For example, some of the writings by C. R. Mann and R. A. Millikan lend themselves to discussions about the purpose of physics education—that is, the theme "why teach physics." Writings by E. H. Hall are particularly useful for discussions about *how* to teach inquiry-based physics using laboratory apparatus.

During class discussions, students will have a tendency to want to speak from their own experiences—whether these experiences are teaching high school or college science, or interacting with the science education research community. The discussion leader should set some ground rules for making personal experiences relevant to the article that is being discussed. Instructors may also wish to require that students use direct quotations from articles as a means for guiding discussion about the main themes of the article.

When we taught the course, we focused each class period on the following student activities:

- describing the key individuals and issues represented in the readings assigned for that class week and discussing relevant questions, generally focusing on curricular issues, physics instructional activities, and the general nature and purpose of high school physics;
- comparing and contrasting specific perspectives of the authors of the readings, with students providing verbatim quotations from the readings that they could use to support claims about authors' views and how these views compare with those of other authors (e.g., How did Hall and Mann differ in their views on the role of the laboratory in high school physics? or How was Dewey's educational philosophy reflected in the physicists' educational models during this period?);
- outlining the social, scientific, and political context of the time period (e.g., a group might be assigned to create a "timeline" of each period containing key names, events, and issues);
- developing and/or answering a set of discussion questions relevant to the key names, events, and issues in physics education (sample questions are provided online; see link in Figure 2); and
- discussing the nature of the physics textbooks used during that time period and how they reflected the rhetoric and concerns of the day.

Conclusion

Much can be gained from looking at the history of science education from a discipline-specific perspective. Although the different science disciplines share many common pedagogical issues, the individual lab activities, problem types, and learning expectations are quite specific to physics, chemistry, biology, and so forth. Similarly, the historical debates and issues addressed by the educators in the various science disciplines had a focus that was in each case specific to that discipline, as we have noted previously.

Furthermore, as we seek change in education, it is important that as many audiences as possible are reached and respond to calls for change. The disciplinary approach to education history brings a very different audience than a broader historical approach to disciplinary learning. Physicists, for example, are interested in physics: They are interested in physics instruction and they are interested in physics education history, much more so than in broad overviews of science education as a whole. A similar statement may be made for scientists in the other disciplines. By appealing to these different audiences, it may be possible to increase awareness about key educational issues. ■

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FIGURE 2, expanded. Key issues, readings, and important questions for each period

A. Origins of physics education in the U.S., 1860-1884

Key readings: Spencer (1860), Huxley (1869), Youmans et al. (1881), Clarke (1881), Wead (1884); *Textbooks*: Quackenbos (1871), Steele (1878), Gage (1882)

Key issues:

(1) Physics was offered by a steadily increasing number of high schools.

(2) A majority of physics instructors professed support for the "inductive method" of instruction.

(3) A few schools began to incorporate individual student laboratory activities.

Questions to consider:

1. Despite the widespread support for the inductive method, there was very little individual laboratory instruction in physics up until this time. What can account for the enthusiasm for the inductive method when there were so few examples of courses taught in this manner?
2. Given that there were few specially trained instructors, and that textbooks and instructional methods strongly emphasized verbatim recall, what were realistic expectations for the outcomes of physics instruction?
3. What design principles motivated Gage's new textbook in contrast to older ones of Quackenbos and Steele?

B. The move toward laboratory science instruction, 1885-1902

Key readings: Hall (1887), NEA (1893), NEA (1899), CEEB (1901), Hall (1902), *Textbooks:* Hall and Bergen (1891), Carhart and Chute (1892), Woodhull and Van Arsdale (1901)

Key issues:

(1) Schools began to institutionalize laboratory physics instruction, which became very widely practiced—even dominant—by the end of the period.

(2) High school courses increasingly resembled college physics courses, with steadily increasing emphasis on mathematical formalism and precise, quantitative experiments.

(3) The Hall "Descriptive List" became the *de facto* standard for selecting experiments to be used in high school classrooms.

Questions to consider:

1. Why did individual laboratory instruction so suddenly (within 20 years) change from a marginal activity to a dominant and required activity?
2. What were the primary learning goals as expressed or implied by (a) Hall's Descriptive List (1887), (b) the NEA (1893) report, and (c) Hall's 1902 textbook on teaching? To what extent were these goals consistent with and/or contradictory to one another?
3. Although colleges began to require quantitative lab work, there were no general college entrance exams until 1901; what, then, could have accounted for the increasing formalization and mathematization of high school physics during this period?
4. How did the pedagogical philosophies used in the textbooks for this period compare and contrast with each other?

C. New Movement Among Physics Teachers, 1903-1910

Key readings: Mann, Smith, and Adams [Circular I] (1906), Circular VI (1908), Millikan (1906, 1909), Hall (1906a, 1906b, 1909), Mann (1909a, 1909b), Terry (1909), Dewey (1910a, 1910b); *Textbooks*: Millikan and Gale (1906), Mann and Twiss (1910)

Key issues:

(1) Increasing numbers of high school and university physics educators complained that the high school curriculum was becoming dominated by colleges.

(2) Only 40% of students were passing the college entrance exam. There was widespread dissatisfaction with the quality of high school physics instruction; "low quality" was attributed to excessive mathematical formalism along with an increasing number of topics, leading to overemphasis on memorization and rote procedures.

(3) The nationwide "New Movement Among Physics Teachers" began when a committee of one college physics professor and two high school teachers was appointed to take "steps as might seem desirable" to improve the quality of introductory high school physics.

Questions to consider:

1. Although reformers such as Mann expressed broad and diverse goals, they focused the questions in the New Movement "Survey" on specifying experiments and curricular topics; why did they do this, and what were the consequences of doing it?
2. What motivated the concerns and/or criticisms expressed by Hall and Millikan regarding the New Movement and its supporters?
3. Although many stakeholders expressed dissatisfaction with the current system, they had difficulty articulating clear, explicit, practical alternative actions. Why was this so difficult?
4. In what ways are Mann's and Millikan's philosophies about teaching reflected in their texts?

D. Project Method, and beginnings of PER, 1911-1914

Key readings: Mann (1912) [selected chapters], Mann (1913, 1914); *Textbook:* Black and Davis (1913a, b)

Key issues:

(1) The project method was seen as a strategy for making physics relevant to "everyday life."

(2) There was increasing recognition of a need for research in physics education.

(3) This was the final period of intense physicist involvement with high schools until the 1950s.

Questions to consider:

1. What was the "project method" as interpreted by Mann and Twiss (1910) and Mann (1912)?
2. What pedagogical issue(s) was the project method intended to address?
3. Does the Black and Davis text provide the necessary structure for implementing the strategies expressed in their Teachers' manual?

E. Reorganization of the secondary curriculum, 1915-1922

Key readings: Barber (1915), Downing (1915), Eikenberry (1915), Twiss (1915, 1920), Millikan (1916, 1917), NEA (1920), Eikenberry (1922) [Chaps. 4, 5, 6], *Textbook:* Dull (1922)

Key issues:

(1) The ever-growing emphasis on teaching "physics for everyday life" focused on technology and use of the project method.

(2) The rise of general science courses was promoted by science teacher educators but treated skeptically by some physicists.

(3) There was a growing gap between the skills needed for desired (project-focused) physics instruction and the actual, limited preparation of typical physics teachers.

Questions to consider:

1. Why do you think the educationists (Barber, Eikenberry, Downing, et al.) promoted general science and nature study?
2. What ideas did the physicists express about the general science course?
3. Contrast the ways in which the ***project method*** was conceived by the physicists and the educationists.
4. What did the educationists mean when they spoke of connecting science to students' lives?
5. What did the physicists (Twiss, Mann, Millikan, et al.) mean when they spoke of connecting physics to students' lives?

F. Dominance by educationists, 1923-1947

Key readings: Millikan (1925), Black (1930), Hurd (1930, 1932), Watkins (1932) [31st Yearbook], Beauchamp (1933), Kilgore (1941), Noll et al. (1947) [46th Yearbook], *Textbook*: Dull (1943)

Key issues:

(1) The "Cardinal Principles" of education and the physics [and technology] of "everyday life" were guiding themes in the evolution of physics curricula.

(2) Education faculty increasingly dominated discussions about physics education.

(3) Education literature expressed a strong perceived need for (but limited action on) research-validated curriculum.

(4) Serious concerns about improving physics teacher education arose in the 1930s and were amplified by post-World War II teacher shortages.

Questions to consider:

1. What issues were addressed in the physics education *research* publications of this period, and in what ways do those issues contrast with those of the present day?
2. How did the "physics of everyday life" as reflected in the textbooks and curricula compare and contrast to the themes enunciated in the NEA (1920) report?
3. How do goals and methods of physics assessment instruments of this period compare to those of the most recent period?
4. In what specific ways did the 31st and 46th Yearbooks either carry forward or revise themes enunciated earlier in the NEA (1920) report and the writings of the New Movement?

G. Re-engagement by physicists, rise of curriculum reform, 1948-1966

Key readings: Arons (1955, 1959), Zacharias (1960), Finlay (1962), Karplus (1964)
Textbooks: Dull (1955), PSSC (1960), PSSC Lab Guide (1960)

Key issues:

(1) There was a proliferation of federally funded, university-based "institutes" for in-service physics teacher education.
(2) After two decades of low involvement, university-based physicists re-engaged with efforts in high school physics curriculum development and physics teacher education.
(3) The PSSC curriculum was introduced and widely disseminated. It focused on core physics principles and lightly guided laboratory instruction, with influence from new guided-inquiry K-6 science curricula.

Questions to consider:

1. What were the similarities and differences between the ideas expressed by PSSC leaders and those of earlier reformers such as the New Movement, the NEA (1920) report, and the 31st and 46th Yearbook Committees?
2. What opinions regarding "traditional" physics education were enunciated by physicists involved with PSSC? What was the evidentiary basis for their opinions? Why do you think they maintained isolation from the science teacher education establishment of the period?
3. How do the PSSC curricular materials compare and contrast both to traditional materials of this period (e.g., Dull [1955]), and to materials and methods used in earlier periods?
4. What were the strategies and goals of physics teacher education and professional development adopted by PSSC? How do these contrast to those of the present day?

H. Culmination of post-war reforms and emergence of modern PER, 1967-1991

Key readings: Strassenburg (1968), NRC (1972), NRC (1973), Reif, Larkin, and Brackett (1976), Hestenes (1979), Viennot (1979), Trowbridge and McDermott (1980), Halloun and Hestenes (1985), Thornton and Sokoloff (1990), Laws (1991), Van Heuvelen (1991)

Key issues:

(1) Physicists initiated studies of students' reasoning abilities and general problem solving skills.
(2) Some physicists focused investigations specifically on student learning of physics.
(3) The first U.S. physics education research (PER) faculty positions appeared in university physics departments.
(4) NSF-funded science curricula were developed in university physics departments, including both K-12 curricula and research-based university-level physics curricula; both had a strong guided-inquiry conceptual emphasis.

Questions to consider:

1. How do the type and methods of engagement in physics education by Karplus, Arons, Reif, and McDermott contrast with each other? How did their activities set the stage for modern PER?
2. In what ways did modern PER reflect the intent of early reform movements?
3. What were some of the central themes of modern PER?

I. Rise of conceptual physics and of modern PER, 1992-2001

Key readings: Heller, Keith and Anderson (1992), Heller and Hollabaugh (1992), AAAS (1993) [Benchmarks], NRC (1996) [Standards], Redish (1994), Reif (1995), Wells, Hestenes and Swackhamer (1995), McDermott (2001)

Key issues:

(1) There was a dramatic and steady rise of enrollment in high school conceptual physics courses.

(2) AIP surveys showed that physics content background of high school teachers was steadily increasing.

(3) There was a significant increase of research-based active-learning physics instruction at the college level.

(4) A broad-based PER community began to develop in university physics departments.

(5) Standards in science education were developed by AAAS and NRC, with attention to specific content standards, common themes among disciplines, and processes of scientific inquiry.

Questions to consider:

1. What were the main perspectives on learning adopted implicitly or explicitly in the PER literature during this time? How were these perspectives applied?
2. Why did PER of this period focus on students' understanding of physics concepts, while conceptual understanding had been relatively so little emphasized in earlier education research?
3. What are some of the specific instructional methods discussed in the literature, and what evidence do authors provide to support claims about the effectiveness of these methods?

J. The present day: High school physics, national reports, 2002-2017

Key readings: NRC (2006) [America's Lab Report], Committee on Prospering (2007), PCAST (2010), Meltzer, Plisch and Vokos (2012), NRC (2012) [Framework], NRC (2012) [DBER], NRC (2013); NGSS (2013)

Key issues:

(1) The number of PER PhDs increased along with the number of Discipline-Based Education Research efforts at universities.

(2) Moves to assess and improve physics teacher quality were on the rise nationally.

(3) A new generation of national science education standards was developed, which incorporated an emphasis on "science practices."

Questions to consider:

1. What are some of the reasons the NRC (1996) "Standards" and AAAS (1993) "Benchmarks" have had only limited national impact, and how do the NGSS (2013) Next Generation Science Standards claim to be different?
2. In what ways and to what extent have research-based curricula found their way into classrooms at different grade levels (e.g., K-8, 9-12, post-secondary)?
3. What is "discipline-based education research"?
4. What are some of the basic findings of physics education research regarding effective methods for teaching and learning physics?

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