SCIENCE EDUCATION IN AMERICAN HIGH SCHOOLS

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The history of education in American high schools is a story of continuous reform. Over the years, practitioners, researchers, and policymakers have advanced a variety of pedagogical and curricular innovations to remedy the deficiencies of those that were themselves once hailed as enlightened and innovative (Tyack and Cuban, 1995). The history of science education—since the appearance of science in high schools in the early 1800s—is no exception. Although the initial argument for the inclusion of science in the curriculum was rooted in the practical value it held for students in a young and expanding nation, other claims have been made as well over the past two hundred years for its inclusion in schools. Justifications for teaching science, the form it assumed, and the audiences it intended to reach have varied considerably from one era to the next, and these variations can be traced to everything from changes in the scientific profession itself to the shifting demographics of public schooling in the United States to, even more fundamentally, the range of social, cultural, and political forces that have shaped the interrelationships among science, schools, and the public.

Two notable themes are apparent when considering the historical place of science in the American high school. First is a continuing tension in the perceived value of science as a subject of study—between the immediate, utilitarian value inherent knowing how natural processes operate in the world and what some have referred to as the disciplinary value of science, the idea that study of the organization and process of science promotes more abstract goals related to morality, virtue, analytical thinking, or aesthetics. From the beginning of high school science education, these perceptions have vacillated between the extremes of the practical-abstract continuum with no sustained trend in one direction or the other. At times, views of science as "practical" have dominated public policy and educational conversations, while at other times, the ability of science study to ensure public virtue and intellectual discipline has held sway among science education advocates.

A second theme, however, has exhibited a discernable sustained shift, with World War II marking the watershed moment. Prior to the 1940s, the form of science education in high schools was predicated on the idea that science had something of value to offer students and the general public, that science provided tools (in either its content or methods) that could be used in other venues or for purposes outside of institutional science. With the historic federal investment in scientific research and development for national security and economic development following the war, science education increasingly aimed at sustaining the professional science community itself, rather than drawing from science to meet the needs of the general public. There was a shift, in other words, from teaching science to make the everyday lives of students and citizens better to teaching science to ensure the success of the scientific enterprise first and foremost. The drawing of broad themes from American history on any topic is, of course, an exercise in simplification, and such is the case with science teaching in American high schools. Some valuable insights might be had based on this account nevertheless.

Early Science Teaching and the High School

Historians typically point to the founding of Boston's English Classical School in 1821 as marking the arrival of the first public high school in the United States. Yet that event by no means heralded the widespread adoption of a new educational institution. The development and dissemination of what many would recognize as the typical American high school happened more gradually throughout the nineteenth century. From the early 1800s through the Civil War, a wide variety of schools provided formal instruction—some tax supported, but most tuition based—to students who had completed their common school studies and were seeking "higher" schooling for a variety of reasons. These types of school included seminaries, academies, and collegiate institutes. Distinctions among schools at this level and institutions of even higher learning—the nation's colleges and universities—were difficult to make throughout this period (Reese 1995; Tolley 2001). What was clear from the outset, however, was the place of science instruction in the course of study these schools offered. In the industrializing, market economy of nineteenth-century America, science in its various manifestations was viewed by its patrons and citizens more generally as a subject of great utility, one that had, in addition, a natural moral and disciplinary foundation (Slotten 1991).

The prevalence of science teaching in early secondary schooling runs counter to a commonly held perception that high schools and academies focused on the study of Greek and Latin, the classical subjects that prepared students for college or university matriculation. Although schools for this purpose certainly existed, the fraction of the population that attended college during this period was far too small to support the comparatively larger number of secondary schools in the country. These high schools, academies, and seminaries survived only by concentrating their efforts on studies that had more immediate value—practical subjects that promised to contribute to the advancement of trade, commerce, and the mechanical arts (Krug 1969; Reese 1995). Geography was the most common early science course offered, well-suited as it was to these practical goals (Schulten 2001). As the United States expanded west across the North-American continent during the early 1800s, knowledge of geography seemed particularly useful and contributed to feelings of national pride. Other subjects that possessed similar practical virtues were gradually introduced as well, including natural philosophy (an early variant of physics), astronomy, chemistry, and botany. All of these were commonly offered in the years prior to the Civil War (Keeney 1992).

Though commonly offered in most secondary schools, these early science courses were not uniformly attended by all pupils. Enrollments in one subject or another varied by geographic area and by gender in particular. Although today the sciences typically are been viewed as boys subjects (at least since the second half of the twentieth century), female academies and seminaries, especially in the

South during the middle decades of the 1800s, enrolled more students in the sciences than comparable male-only institutions. This is explained partly by the fact that boys from families of higher socioeconomic status were more likely to be engaged in preparatory work for college, which, given the entrance requirements of the time, entailed mastery of the classical curriculum. With colleges generally not open to women before the Civil War, pursuing classical study made little sense. Girls were encouraged instead to pursue more practical subjects and those that possessed disciplinary and moral value. This resulted in higher numbers of girls in science courses up through the 1890s when colleges began to matriculate women (Tolley 2002).

The perceived moral and disciplinary attributes of science were important factors in the subject's incorporation into the secondary school curriculum during the nineteenth century for boys and girls alike (Hollinger 1984; Slotten 1991; see also Guralnik 1975). If narrow utilitarian advantage were all the sciences could offer, these subjects would likely have been limited to trade, vocational, and specialized engineering schools. Advocates of chemistry, botany, and zoology, however, insisted that subjects like these had the power to reveal the work of God in nature. The study of science, they argued, would bring students closer to the divine, which was no small aim in the era of religious revivalism and natural theology of the early and middle 1800s (Ahlstrom 1972). Complementing this spiritual benefit was the belief that science had the ability to develop the intellectual faculties of the mind in the same way that study of the classical languages did. Psychological theories viewed the mind as an organ that, much like a muscle, could be developed through exercise. Grappling with the precise, rigorous structure of scientific knowledge, many believed, produced mental discipline of the highest level, at least on par with that derived from classical study.

As the forces of industrialization extended across the United States, the sciences moved to occupy a central place in the high school curriculum. This move reflected the growing American faith in science and technology as a means of economic and social advancement. The spiritual and intellectual virtues were also recognized and promoted, but it was the practical payoff in the end that secured the place of science in the curriculum. In a collection of widely circulated essay's published in 1861, the British political theorist and polymath Herbert Spencer famously asked "What Knowledge is of Most Worth?" His answer, without hesitation, was "science," knowledge of which by his reckoning could be fruitfully applied to nearly all of the affairs of life. Following this line of reasoning, Congress passed the Morrill Land-Grant Act in 1862, which led to the establishment of state universities charged with disseminating useful knowledge in agriculture and engineering nationwide (Geiger 1998). These operated alongside private schools devoted to the advancement of the mechanical arts and industry, such as the Massachusetts Institute of Technology and the Stevens Institute in New Jersey, which grew up in the decade after the Civil War.

This rising tide of interest in the practical led a number of states in the 1870s to institute natural science requirements in their elementary teacher certification exams. This, in turn, generated even greater emphasis on science in the high schools, which were the institutions (along with normal schools) that were primarily responsible for the preparation of school teachers in the lower grades

(Ogren 2005). By the middle 1880s, the public high schools had eclipsed private academies and seminaries as the primary institution for secondary education in the United States, and the sciences were firmly established as central components of their curriculum (Krug 1969; Reese 1995).

From Textbooks to Laboratories

The relationship between forms of subject-matter knowledge and its social value is worth examining carefully in the case of science. The perceived utility of the sciences in the middle decades of the nineteenth century derived, for the most part, from the factual knowledge about the world that scientists sought to accumulate. Accordingly, some educators classified subjects such as chemistry, botany, physics, and the like as "information-giving" subjects, whereas the value of other subjects, such as mathematics and the languages (whether modern or classical) derived from their ability to "discipline" young minds. This division was seen as particularly appropriate in the common schools and high schools where practical application was regarded more highly than intellectual exercise (though science was believed capable of both). Seeing the contributions of science this way—a view common in the 1860s and 70s—led textbook authors and teachers to a pedagogy of transmission. Teaching science, in other words, entailed the careful study of the systematized knowledge of the subject in question, typically through the canonical textbooks of the time. Instruction most often involved student rote memorization followed by recitation of the facts learned (Reese 1995). More innovative teachers might have interspersed their lessons with a scientific display or demonstration. Alternatively, they may have organized their lesson around an object brought into the classroom following the Oswego method that came out of upstate New York in the 1860s, though such practices were far from common.

During the 1880s, some university science faculty and high school science teachers pushed to move beyond sterile textbook approaches to science instruction. Invoking Harvard zoologist Louis Agassiz's oft-repeated maxim to "study nature, not books," educators in the second half of the nineteenth century pushed for students to confront nature directly, either in the field or laboratory (Owens 1985; Kohlstedt 2010). Agassiz himself led Boston-area teachers out into the field to learn from nature first hand at his island summer school off the coast of Massachusetts. In this same spirit, laboratory work had been introduced earlier at specialized technical schools such as Renessalear Polytechnic and the Massachusetts Institute of Technology, founded in 1824 and 1864 respectively. Such instruction, though, was aimed primarily at preparing students seeking careers in the industrial and technical fields opening up in the United States at the time (Angulo 2008; Kremer 2011).

Laboratory instruction as a means of general education, or liberal study, however, came only after the incorporation of teaching laboratories into the larger universities and liberal arts colleges of the United States. In the 1850s and 1860s, Harvard University set up such laboratory space in chemistry and physics with the encouragement of its president Charles Eliot. As the land-grant universities got their footing following passage of the Morrill Act, they too instituted laboratory instruction in many of their introductory science classes

(Geiger 1998; Keeney 1992). Johns Hopkins University, founded in Baltimore in 1876, provided perhaps the epitome of a university committed to the laboratory teaching ideal, serving as both a model of instructional approach and an incubator for science faculty dedicated to teaching via laboratory methods (Owens 1985).

The impetus for the shift from textbook study to laboratory teaching can be traced in part to the professionalization of science in the United States during this period (Higham 1979). This was shaped by a growing enthusiasm for the German research ideal that young scientists brought back with them from their studies abroad during the 1870s and 1880s. German universities in the second half of the nineteenth century embraced a research and teaching ideology grounded in the ideals of *Lehrfreiheit,* the freedom to teach as one saw fit, and *Wissenschaft,* the pursuit of broad-based inquiry or research. American scientists studying in places like Göttingen, Berlin, and Munich returned to their own institutions in the states with an enthusiasm for a higher education dedicated to pure research and learning. Following their German academic role models, they were little concerned about the ultimate utility or practical application of their research. The American version of the German ideal was heavily focused on the natural sciences and laboratory work, which was believed to be central to the advancement of science both in research and teaching. Teaching laboratories were, in fact, well developed already in the United States. But they were increasingly viewed by the growing community of American scientists an essential element of the modern research university (Veysey 1970, Geiger 1998; Roberts and Turner 2000).

Laboratories in the High Schools

Given the blurred boundary between colleges and universities and the secondary schools of the time, it is not surprising that high school science teachers rapidly adopted laboratory teaching. Seeking to promote this new instructional approach as widely as possible, university faculty and high school science teachers wrote new textbooks designed for use in laboratory settings. In addition, the growing number of graduate programs at American universities graduated more and more new science PhDs trained in the new methods and committed to the research ideal. These were students who, upon seeking gainful employment, often took up positions in the new high schools being built in towns and communities as part of the growing expansion of public schooling at the time (Olesko 1995; Kohler 1996; Rudolph 2005a). The porous boundary between university and high school, thus, allowed the flow of not only the new professional vision of science with its particular, German-inspired methods, but also personnel—the teachers and textbook writers—who re-fashioned emerging high school science teaching practices in ways that mirrored those in the university (Hoffman 2011; Turner 2001). As much as these various agents of change moved school science practice toward the new ideal, college admissions requirements were, perhaps, the more powerful lever for reform; in the mid-1880s, revised college admission requirements had a profound effect on the spread of laboratory instruction in the sciences.

Many current scholars, as well as science educators who lived through the transition, point to the introduction of a laboratory option in the entrance requirements for physics introduced at Harvard University in 1886 as the tipping point in the widespread adoption of laboratory methods (Rudolph 2005a). Aspiring Harvard students electing the laboratory option were required to demonstrate their manipulative skills in a laboratory practical exam on campus in addition to submitting a laboratory notebook documenting their completion of forty specific physics exercises, often completed during the student's senior year of high school. The physicist Edwin Hall, who had been recruited by Harvard president Eliot in part for his experimental talents, was charged with overseeing the development and implementation of the laboratory examinations. In hiring Hall, Eliot tapped into the growing network of scientists who were committed to laboratory teaching, people like the Johns Hopkins chemist Ira Remsen and physicist Henry Rowland (also at Hopkins), under whom Hall had earned his PhD. Hall was a powerful advocate of both laboratory teaching and Harvard's new examination option. He widely advertised the revised admissions policy in scientific and educational circles, fully expecting area highs schools to adjust their course offerings to meet the new expectations. (Rosen 1954; Moyer 1976; Rudolph 2005a).

The Harvard admissions requirement in physics was, of course, not solely responsible for the adoption of laboratory methods in American high schools. Some scholars have argued that Hall's role in the transformation of science teaching during this period has been overstated (Turner 2011) and that the new laboratory-based physics curriculum was, in reality, an amalgam of ideas and materials that were in the air at the time. It would be a mistake to argue otherwise; there were without question numerous factors, both in and outside of Cambridge, that contributed to what many have described as the national "craze" for laboratory teaching that took hold at the end of the nineteenth century. What should not be minimized in all this, however, is both the real and symbolic role that Hall and Harvard assumed in the perceptions of this particular educational reform movement. In a history of science teaching written in 1909, one influential science educator reflected on the rapid embrace of laboratory teaching noting that the "college entrance requirements have been of the greatest assistance in hastening this progress." "Physics teaching," he continued, "owes a great debt of gratitude to the colleges generally, but to Professor Hall and Harvard in particular" (Mann 1909, p. 793).

Although not as well chronicled as the move to laboratory teaching in the physical sciences, the biological sciences experienced a similar transformation of teaching practices in the high school. The push for reform came on two fronts, one from the plains state of Nebraska and the other from overseas in the United Kingdom. The eminent botanist Charles Bessey was the domestic agitator for reform. Teaching and writing initially at Iowa State College in Ames, Bessey became a strong voice for laboratory teaching following his move to the University of Nebraska in Lincoln in 1884. He worked closely with teachers in the region providing guidance on how to set up and run a school laboratory, lending specimens to local classrooms, and teaching summer-school courses that modeled appropriate pedagogical practice. His popular high school botany textbooks had far greater reach, spreading the laboratory approach to all corners of the country. From across the Atlantic, the influential zoologist Thomas Henry Huxley busily shaped the study of the biological sciences as well. Huxley had a strong interest in promoting greater public understanding of science, and his 1876 textbook, *A Course of Practical Instruction in Elementary Biology,* set a new standard for a laboratory-based approach to life science instruction quickly sparking the publication of a number of American textbooks following Huxley's template. (Tobey 1981; Keeney 1992).

Although the adoption of hands-on teaching methods in high school subjects like botany, zoology, and physiology lagged somewhat behind the changes in physics and chemistry, by the end of the century, students in the life sciences spent considerable time engaged in a variety of laboratory and field work. They gathered and dissected specimens, built herbaria, learned the intricacies of microscopic observation, and assembled museum-like classroom displays among their many activities (Benson 1988; Conn 1998; Rudolph 2012). For many educators (and the public), such work continued to be justified by the remnants of natural theology—a worldview that held that the study of nature was in and of itself virtuous, revealing as it did the beauty and wisdom of God's design in nature. The content of high school courses in zoology and botany, however, was organized around seeing the morphological features of plants and animals as environmental adaptations and understanding the evolutionary relationships among organisms and their place in broader systems of classification—learning outcomes thoroughly grounded in science rather than theology. (Pauly 2000; Rudolph 2012).

The move to laboratory instruction across all subjects in American high schools was solidified in 1893 with the publication of the *Report of the Committee of Ten on Secondary School Studies*. Under the leadership of Harvard president Charles Eliot, this report became the de facto educational standards document of the time. The final version included recommendations from subcommittees covering all the primary high school subjects taught at that time. In the sciences the list spanned physics, astronomy, chemistry, botany, zoology, physiology, physical geography, geology, and meteorology. As Eliot summarized, "All the Conferences on scientific subjects dwell on laboratory work by the pupils as the best means of instruction," an emphasis he heartily endorsed naturally. From the publication of the Committee of Ten report through the first decade of the twentieth century, laboratory methods spread throughout the country. By the early 1900s, the most common science subjects in high schools were botany, zoology, chemistry, physics, and physiography (or geography) all taught with an emphasis on laboratory study. Laboratory teaching, advocates insisted, not only captured the essence of scientific work, but also provided an effective path to mental discipline and moral rectitude, much as the study of classical languages had years earlier. Such thinking marked a clear shift from earlier justifications for science teaching derived from the practical utility of factual knowledge about the natural world.

The Progressive Vision of Science Education

Early in the twentieth century, a new vision of science education emerged to challenge the course of study and pedagogical approach endorsed by the

Committee of Ten Report the previous century. Informing this vision was the rapid expansion of the educational enterprise in the United States that began at the university level during the 1890s and extended with amazing speed to the high schools over the subsequent decades. This expansion resulted in a push for a radically different kind of science education in the nation's schools—a science education designed to address student everyday needs and interests rather than following the abstractions at the heart of the scientific research establishment.

The explosion in high school enrollments during this period was nothing short of astounding. From 1885 to the end of the century, the total number of secondary school students went from approximately 132,000 to nearly 650,000, a fivefold increase over a span of only fifteen years. During the first two decades of the twentieth century, school enrollments further quadrupled reaching 2,757,000 by 1920. The flood of students, not surprisingly, stimulated a school building boom. Over the two decades spanning the turn of the twentieth century, an average of one new high school was built every day to accommodate the growing numbers of students. As enrollments increased, a consensus emerged among educators that the masses of students now populating the schools had decidedly different educational needs than their predecessors. The percentage of students engaged in high school study as preparation for college (though always small), shrunk even further to single digits. More troubling, even, was the fact that the overall student enrollments in the sciences were declining at an even greater rate proportional to enrollments in other traditionally academic school subjects like Latin. The majority of students now in attendance increasingly were viewed as needing more practical and personally relevant instruction in contrast with the formal disciplinary studies that had been common to that point (Krug 1969; Kliebard 2004; Rudolph 2005b).

As the size of the student population grew, so too did the number of high school teachers, who were prepared in the growing number of graduate schools, universities, and colleges across the country. These individuals found common cause teaching their new student clientele and began to rethink the mission of the schools. In an era of professionalization, they formed associations, organized regional and national meetings, and launched journals dedicated to articulating an alternative vision of what a high school education should accomplish. In the sciences, this professional energy was channeled into the Central Association of Science and Mathematics Teachers (CASMT), founded in 1901, the most prominent and far-reaching organization of its kind. Science teacher leaders from this group drew on ideas from the young field of educational psychology and child study promoted by individuals such as G. Stanley Hall of Clark University (who wrote the book *Adolescence* in 1904) and John Dewey, then at the University of Chicago, to inform their thinking about what school science education should look like in the new century. The needs and interests of students, they insisted, should chart the course of the science curriculum. The logical organization of the disciplines, although important, would take a back seat to the everyday experiences of children that would provide the personal motivation and social justification for learning science (Ross 1992; Rudolph 2005b; Smuts 2006).

The push for change began with what was called the "new movement among physics teachers." Beginning in 1905, leaders of this reform group—mostly teachers and officials of CASMT—called for a radically different approach to physics teaching that would break free of the standard forty descriptive laboratory exercises put forward by Edwin Hall and Harvard University. Drawing on the work of the new psychologists, they argued that physics teaching needed to be made more interesting and relevant to students. That the dry, quantitative laboratory exercises of the past should be replaced by more qualitative exercises or even replaced entirely by teacher demonstrations or illustrated lectures that made real connections between physics and the world in which students lived (Moyer 1976; Olesko 1995; Rudolph 2005a). Although not the direct target of reformers as was physics during these years, high school chemistry experienced similar pressures to shift away from the sterile academic presentation of the discipline toward more practical and applied treatments that were likely to appeal to the non-college bound students of the subject (DeBoer 1991; Cotter 2008).

The Appearance of Biology and General Science

During this period of curricular unrest two entirely new school science subjects made their debut—biology and general science. Prior to the turn of the century, the life sciences manifested in the secondary schools in the form of zoology and botany and, where necessary, physiology, a subject mandated in many states as a means of checking the spread of alcohol consumption (Pauly 1991; Zimmerman 1999). Although educators debated which of these subjects provided the best introduction to the life sciences for high school students (most often botany with its easily accessible laboratory material and more direct connection to students' lives won out), schools increasingly offered the two subjects in consecutive semesters to provide a general survey of living organisms.

Whether studying plants or animals, students were instructed in true natural history fashion to assemble collections of insects and plants, dissect specimens, and make careful drawings to record their observations. The focus of learning was typically on having students appreciate the marvels of adaptation of organism to environment as well as to understand the broader relationships among organisms—that is, how they fit into a natural order, a system of classification. Such schoolwork work was initially pursued within the framework of natural theology (as testimony to the wisdom of the Creator) but shifted over time—with little change in actual classroom work—to embrace (and demonstrate) evolutionary relationships as evolution increasingly took hold in the sciences and in American culture more generally (Pauly 2000; Numbers 1998; Rudolph 2012).

By 1905, the fused botany-zoology curriculum had transformed into the more familiar school subject, biology. This new subject first appeared in the urban high schools of the northeast where large numbers of immigrants streamed into the growing public school systems. As part of the reform movement aimed at student interests and social relevance, the new biology textbooks covered many of the traditional topics common to earlier botany and zoology courses while expanding their scope to topics such as hygiene, personal nutrition, ventilation, urban sanitation, and sex and reproduction (though this last topic was taught indirectly without direct reference to humans). By the mid 1920s, high school biology had become a staple of the high school curriculum most often required at the sophomore level and designed to teach the human animal, following the progressivist thinking of the time, how to live better. The conditions of the time created a pressing need, biology educators asserted, for adolescents and those new to America to themselves adapt to their increasingly urban industrial environment (Pauly 1991).

Joining biology in the high schools during this period was general science. Offered most frequently as an introduction to science for high school freshman, the development of this course was a response to what many in the new professional education establishment saw as the overspecialization of the discipline-focused courses of physics and chemistry. Borrowing heavily from the early psychological work on student interest and John Dewey's writing on the nature of rational thought, proponents of the general science course sought to engage students in a survey of science topics common in everyday experience. This approach dispensed with disciplinary structure altogether foregrounding instead a universal method of problem solving modeled on scientific thinking. This, proponents insisted, not only captured the essence of science as an enterprise, but also provided something of real value and utility for the majority of students then attending high school. Here was a skill, they maintained, that had practical payoff in students' lives.

From the emergence of general science as a distinct course in the nineteen teens through the 1930s, the problem-solving approach described above quickly transformed into what came to be known as project-based teaching. This pedagogical approach—following the trend toward the practical—had students study, among other things, the best methods for ventilating their classroom, the proper operation of a home furnace, or methods of drinking water filtration. General science pursued by means of the project method ended up, in many ways, as a course in civic engineering, at least in the urban areas where it first took hold. (Heffron 1995; Rudolph 2005a; 2005b).

The changing curricular emphasis of these subjects on the everyday and utilitarian in contrast to the disciplinary and academic aligned with broader curricular shifts occurring in education at the time. The most well known marker of this shift was the publication in 1918 of the National Education Association's *Committee on the Reorganization of Secondary Education,* commonly referred to as the Cardinal Principles Report. This was a national statement of educational policy that turned sharply from the recommendations of the Committee of Ten, which had set the pattern for high school instruction thirty years earlier. In place of calls for the focused study of the disciplinary knowledge and praise of the virtues of rigorous laboratory work, the Cardinal Principles Report called for education that would promote, among other things, health, worthy home membership, citizenship, ethical character, and worthy use of leisure time. The only goal mentioned in the report having an academic cast was the "command of fundamental processes," which covered the skills of reading, writing, and mathematical calculation. The subcommittee report on science, which was published two years after the main report, echoed these goals, placing heavy emphasis on general science as one powerful way of accomplishing them (DeBoer 1991; Kliebard 2004; Rudolph 2005b).

The new subjects of biology and general science enjoyed tremendous success in the early decades of the twentieth century. From 1910 to the mid-twentieth century, general science textbooks and courses proliferated. Hundreds of new textbooks appeared on the market and every state in the union could point to school districts offering the new course. In 1941, nearly three quarters of all science courses offered at the freshman level were general science. The spread of biology as a high school subject was equally impressive with the subject making up 79% of all science offerings at the sophomore level. These two school subjects, developed as they were for the general education of the average citizen represented a faith and optimism in the role science could play in the progressive amelioration of the difficult conditions of the new industrial age. Chemistry and physics, although serving a smaller number of students at the junior and senior levels of high school, similarly sought to appeal to the everyday interests of students at the same time they introduced them to more formal disciplinary structures for those in the college-preparatory track. Through all these subjects, educators believed that an understanding of scientific thinking and its application to the material and social problems of everyday life could do much improve the human condition.

The Scopes Trial and Its Fallout

The progress science education made during this period extending its secular vision of society through the dissemination of mechanistic accounts of natural processes along with a universal method of thinking was not welcomed by all. There were social and cultural groups in the United States that resisted the worldview associated with this progressivist manifestation of science. None objected more strongly, perhaps, than the conservative Christian groups that coalesced into the religious fundamentalist movement during the early 1920s. Leaders of this movement viewed modernist thinking of the time with its evolutionary assumptions as a threat to traditional moral values and promoting militarism and even communism in one form or another. This cultural clash came to a spectacular head with the trial of John Scopes in Dayton, Tennessee in 1925.

The Scopes trial pit famed courtroom litigator and agnostic Clarence Darrow against the fading political giant and antievolution crusader William Jennings Bryan in a debate over the truth of scripture versus the truth of science. This courtroom contest was one of the most significant media events of the first half of the twentieth century. The events that transpired those hot August days in Tennessee transfixed people across the United States and beyond. On the one side was Darrow advancing not only the modern, scientific account of life on Earth and the historical path of its evolution, but representing more broadly the power of science as a means of social improvement—a view that permeated progressivist thinking of the time. On the other side was the three-time Democratic presidential candidate and gifted orator Bryan, who even in his declining years commanded national attention. Bryan objected to an evolutionary worldview that provided cover for the social and economic elite through its "survival of the fittest" mantra. Even more troubling to Bryan was the damage such thinking would do to the country's religious faith; and teaching evolution to the nation's impressionable school children was a practice likely to actively undermine that faith.

While there was much give and take over where the truth really lay (the Bible or science) both in the streets of Dayton as well as in the national press (just what the town boosters had hoped for in orchestrating the trial), the legal point at issue was more mundane, having to do with whether the state could regulate the content of the curriculum. Scopes, having admitted to teaching from a biology textbook that included evolution in violation of state law essentially conceded this point and was convicted (though it was set aside on a technicality). (Larson 1997; Marsden 2006; Shapiro 2008)

The impact of Scopes trial on high school biology teaching has been much debated. It had been widely held that the event marked a significant retreat from the teaching of evolution in the schools. Terms like "evolution", "natural selection", and "Darwin" nearly disappeared from the tables of contents, indexes, and glossaries of most high school biology textbooks after 1925, the result of the big publishing companies of the time scrubbing from their books easy-to-spot references to the controversial topic in an effort to maintain sales numbers. Scholars have offered different accounts of this curricular pull back from evolution. Although some have, indeed, viewed the elimination of evolution and related vocabulary as an abdication of sustained engagement with the topic, others have argued that these changes were merely superficial and did little to overturn the broad, scientific and cultural commitment to the progressive evolutionary ideas the biology textbook authors were most invested in. The content of biology as it appeared in textbooks throughout the first half of the twentieth century, in other words, was the story of the evolutionary progress of life on Earth, humans included. (Skoog 1979; Pauly 1991; Larson 1997; Ladouceur 2008).

From the 1930s to the 1950s, science education followed the general trend toward the personal and the practical as advocated by the Cardinal Principles Report of 1918, but all in the context of the country's democratic political system. With universal high school education increasingly accepted as a social norm, school districts continued to cater to student interests and the wide range of student ability in the nation's classrooms. All the standard high school science subjects from general science at the freshman level through biology, chemistry, and physics in the upper grades included heavy doses of applied science and technology, textbooks were filled with examples of objects and appliances students were likely to encounter in their daily lives. One could read about everything from the biological principles of proper nutrition and personal hygiene to the physics of home refrigerators and industrial steam shovels. The focus in science education on personal and social problems, projects, and activities reflected the dominant progressive social engineering ideology of education in these decades leading up to World War II.

With respect to the process of science, students were regularly fed a diet of the "scientific method," which typically consisted of five steps (beginning with the identification of a problem and ending with its resolution) often taught by rote that could be algorithmically applied to nearly any life situation or natural phenomenon. Skill in rational thinking was deemed essential for public engagement in democratic processes. The safeguarding of democracy was seen as a high priority as totalitarian regimes spread across the globe in the late 1930s and 1940s (DeBoer 1991; Rudolph 2005a; Hollinger 1990).

Sputnik and the Cold War

During World War II the business of schooling centered on wartime mobilization. Few innovations were introduced that had any lasting effect. The years following the war, however, present a different picture altogether as American society experienced dramatic economic, social, and cultural changes. The federal government began to heavily invest in scientific research and development; the baby boom that started in the 1950s drew increasing attention to national educational policy and infrastructure; the launch of the Soviet satellite *Sputnik* ratcheted up national security concerns; and the popular counterculture movement that emerged later in the 1960s forced citizens and policymakers to rethink the role of science in society.

The American high school was naturally swept up in these changes, and science education, in particular, was a popular target of reform. Through the newly established National Science Foundation (NSF), which was founded in 1950, the federal government took on unprecedented financial and bureaucratic roles in the development and dissemination of new curricular materials in the sciences during. Spurred by a commitment to academic excellence and growing concerns about Soviet scientific advances, federal administration officials and legislators saw improving science education for the baby-boom generation as a national priority (Atkin and Black 2003; Reese 2011).

Science education was far from the only area undergoing profound changes during the 1950s—federal education and scientific research policy were transformed as well. A fundamental shift occurred in the realm of education policy—educational issues that had traditionally been handled locally were moved onto the national stage. The Supreme Court's 1954 decision in Brown vs. Board of Education of Topeka, Kansas, which held that segregated schools for African Americans and whites were inherently unequal, positioned the federal government as a force to implement change at the local level (Patterson 2002). In addition, federal legislation, such as the National Defense Education Act (NDEA), passed by Congress during the Eisenhower Administration in response to Sputnik, and the Elementary and Secondary Education Act (ESEA) in 1965, as well as the establishment of institutions like National Science Foundation and the upgrading of the Office of Education into a cabinet-level body in 1953, placed education, science education, and science policy squarely on the federal agenda (Kaestle and Smith 1982; Kleinmann 1995; Kevles 2001; Urban 2010). Taken together, these various agencies and laws transformed the relationship between scientists, educators, schools, curricula, and students. This legacy of these changes, especially the active involvement of scientists recruited to develop new science curriculum materials and the role of the federal government in science and science education, remains with us today.

Science education scholars have tended to mark the launch of Sputnik in 1957 and the subsequent passage of the NDEA as the turning point in federal involvement in science education (Clowse 1981; Kaestle 2001; Urban 2010). The impetus for reform, however, occurred several years earlier. Concerns about the adequacy of high school physics, for example, were voiced as early as 1951 in meetings of the government's Science Advisory Committee in the White House

Office of Defense Mobilization. These conversations led Massachusetts Institute of Technology (MIT) physicist Jerrold Zacharias to assemble the *Physical Science Study Committee* (PSSC) in 1956.

Riding the wave of popular support for scientists after their military successes during the World War II, Zacharias used this group to push for an updated high-school physics curriculum. Using PSSC as the vehicle for reform, Zacharias, with the support of NSF, led a group of nationally recognized physicists in the development of a new, cutting-edge high school physics course. In addition to upgrading the quality of high school teaching in this subject, PSSC offered a concrete way for the scientists to assert their social capital, promote their view of disciplinary knowledge, and defend the utility of science to society. What was deemed useful to society, however, was basic, or "pure", science rather than applied science or engineerying. Drawing from the military models and organizational structures they experienced during the war, these scientists hoped that the new science education they were constructing would in the long term insure continued federal financial support for basic scientific research, a goal they believed was essential to the survival of the United States in the new scientific age (Rudolph 2002b).

Their pedagogical positions were buttressed by popular books such as Arthur Bestor's scathing attack on progressive curriculum of the pre-war years in *Education Wastelands* (1953) and Jerome Bruner's book *The Process of Education* (1960), which provided a psychological framework that was used to justify the new curricular focus on disciplinary knowledge in preference to the past emphasis on what was increasingly viewed by the public as the "soft" personal and applied aspects of school subjects. (Rudolph, 2002a).

The Golden Age of Science Education

PSSC was not the only scientist-led group assembled to reform the high school science curriculum. Spurred by the crisis atmosphere generated in the wake of Sputnik, these MIT reforms were soon followed by other curriculum development projects directed by scientists from top research universities across the country. In biology, Florida zoologist Arnold Grobman and Johns Hopkins geneticist Bentley Glass launched the *Biological Sciences Curriculum Study* (BSCS) at the University of Colorado in Boulder. In chemistry two projects were initiated, the *Chemical Bond Approach* (CBA), under Arthur Scott of Reed College, and the more popular *Chemical Education Materials Study* (CHEM Study), led by Berkeley Nobel laureate Glenn Seaborg. Other new curricula followed including the *Earth Science Curriculum Project* (ESCP) and *Introductory Physical Science* (IPS) among others.

The approach taken by what many refer to as the alphabet curricula was grounded by the belief that as long as these courses accurately reflected the scientific discipline under study and teachers were properly trained to use the new material, then success and student achievement would surely follow. A common theme among these projects was an emphasis on what came to be referred to as "scientific inquiry"—the process through which scientists arrived at their knowledge about the world. Scientific inquiry was often taught often through direct participation in laboratory activities, although text-based exercises in data analysis and the careful reading of original scientific work were used as well. The idea underpinning the emphasis on inquiry—that the process of science could only be properly understood and appreciated from within the disciplinary structures that informed it—stood in sharp contrast to the views of science advanced by the Progressive Era educators who believed that the methods of scientific thinking could be applied to any project or problem independent of the disciplinary structures from which they originated. According to the cold-war scientists involved in these projects, the idea of a universal "scientific method" was a myth. Science was an enterprise best practiced by scientists themselves and properly funded by the general public.

The strong interest the scientist-reformers had in controlling the view of science presented to the public in schools was evident in the curriculum materials they produced. Among the key techniques used by these groups, for example, was the widespread incorporation of instructional films and film loops into the teaching packages they developed, which allowed the scientists in some instances to bypass teachers and reach students directly on a massive scale. Indeed, scientists during this period tended to play up their image as saviors for science education, often claiming that their new materials were replacing textbooks filled with errors and misrepresentations of both science content and process.

Nowhere was this type of rhetoric as clearly in full view as in biology. The directors of BSCS, in an effort to promote their own product as modern and cutting edge, maligned biology textbooks from the pre-war era for their removal and exclusion of Darwinian evolution. They claimed that authors and publishers of existing textbooks were pandering to religious demands in a post-Scopes marketplace, downplaying and even hiding evolution in their textbooks in various ways in order to enlarge their market share. This narrative allowed the BSCS team not only to offer their own textbooks as a necessary update, but it also enabled scientists to position themselves as guardians of proper scientific pedagogy (Larson 2003; Rudolph 2002a). Some scholars, however, have questioned this simplified narrative, arguing that the directors of BSCS, intentionally or not, misrepresented the work of earlier biology textbook authors whose books did include significant references to modern evolutionary ideas even after Scopes (Ladouceur, 2007).

Many have described this period, from the late 1950s through the 1960s, as the "golden age" of high school science education in the United States. And it was golden from a resource perspective to be sure. Federal money to improve science teaching flowed at all levels, from curriculum to teacher professional development to classroom materials. The NSF, with the full backing of Congress, took the lead on the curriculum and teacher-quality front, funding the scientist-led textbook writing projects as well as scores of summer teacher-training institutes across the country designed to enhance the content knowledge of the nation's high school science teachers (Krighbaum and Rawson 1969). Resources from the National Defense Education Act were sent directly to local school districts by the United States Office of Education. Among the NDEA's provisions was Title III, which provided hundreds of millions of dollars for local schools to purchase science equipment and apparatus and to modernize their laboratories and teaching facilities (Urban 2010; Rudolph 2012).

The Humanistic Turn

Despite the warm welcome they received in some quarters, the discipline-centered curricula had detractors as well. By the mid-1960s educators and scientists alike began to complain that curricula like PSSC reached only an elite group of students—mainly upper-middle-class, Caucasian males, leaving women, minorities, and those without any particular aptitude for science behind. They faulted the strict disciplinary notion of science presented in the textbooks, which, they believed, precluded the more nuanced and humanistic elements of science that might appeal to non-traditional science students. Partly in response to critiques like these, NSF began supporting a second wave of curriculum efforts in the mid 1960s. The most prominent of these was *Harvard Project Physics* (HPP), a high-school physics curriculum led by Harvard physicist and historian of science Gerald Holton along with F. James Rutherford and Harvard education professor Fletcher Watson. HPP sought to provide an alternative to the technical physics of PSSC by presenting the subject through a more humanistic lens. They drew specifically from the relatively new field of history of science to provide a richer social and cultural context of the subject's development over time.

Other second-wave projects included initiatives to extend reforms down to the lower grades through curricula such as *Science–A Process Approach* (SAPA) and the *Elementary Science Study* (ESS), as well as to move beyond the natural sciences to the social sciences as was done with the project Man: A Course of Study (MACOS) directed by Harvard psychologist Jerome Bruner. Proponents of these second-wave science curricula claimed that by softening the image of science, they could increase and widen student enrollments and interest in science courses. Furthermore, according to many educators, courses like PSSC were blissfully ignorant of teachers' real needs in terms of materials and instructional flexibility. These curricular alternatives were presented as a way to give teachers choices that would allow them to respond to the needs of their students. (DeBoer 1991; Dow 1991).

The transition in the mid 1960s from the narrow focus on the technical practices of disciplinary practice to a more open and humanistic science education was aligned with the broader cultural and social movements of the period that questioned the value and practices of the professional science establishment. This happened at both ends of the political spectrum. BSCS's brash reinsertion of evolution in biology textbooks sparked considerable reaction among a revived religious community on the right that rose up to battle the scourge of Darwin much as it did in Dayton, Tennessee forty years earlier. And on the left people across the country were staging sit-ins against the Vietnam war, demanding that universities cut their research ties to military contractors and private corporations, and founding organizations devoted to directing scientific knowledge and resources toward the public good. People also took to the streets, demanding equal rights for all. Science was not immune from such critiques. Not only did everyday citizens begin to question the power and authority of science, but professional scientists joined the chorus as well, challenging science's premise of a better world as well (Vettel 2006; Moore 2008). By the 1970s the reforms of the 1960s had failed, ultimately collapsing under the weight of high expectations and the difficulties of changing longstanding school structures and classroom practices.

STS and Scientific Literacy

If the 1960s were the heyday of science education reform—an era of lavishly funded curriculum projects directed by high-status, nationally renowned scientific researchers who had the attention of officials at the highest levels of government—the 1970s were nearly the opposite. The enthusiasm for fixing high school science teaching through large-scale curriculum reform and new teacher-training programs waned in the face of entrenched school practice, social unrest, and a new skepticism of the social value of science. Even Jerrold Zacharias, the generally upbeat head of PSSC (the project that had set the pattern for those that followed) recognized the immense challenge such efforts faced.

Funding for new projects was a particular challenge during this time. Money for curricular development from governmental agencies like NSF began drying up in the early 1970s and was finally cut off in 1975 after public objections to the ideas included in the social science project *Man: A Course of Study* (MACOS), which, critics argued, undermined family values and promoted cultural relativism. Federal funding of educational materials for use in local schools had been a sensitive issue from the beginning, and the controversy over MACOS alongside a faltering national economy and public disillusion with scientists and other experts in the mid 1970s made shutting down federal involvement in curriculum work an easy decision. Scientists slowly migrated away from the world of high school science education, leaving it the sole domain of educators once more. With the country settled into a long, cold war with the Soviet Union and facing new challenges on economic and political fronts, the sense of urgency that had attended science education in the post-Sputnik era largely disappeared. Promoting student excellence and achievement in science receded in importance, and educators were in many ways freed from federal and political expectations (Dow 1991; Milam in press).

Following in the spirit of those who had advanced a student-centered, socially relevant science curriculum from the 1920s through the 1950s, educators in the 1970s were once again free to assert their vision of what high school science might accomplish. They argued for a curriculum that would engage students with social and technological issues that were personally meaningful to them. This meant infusing science teaching with the dominant social and political issues of the day. Issues of racial, social, and economic inequity moved from the political world to the classroom, as did concerns over the environment. This reversed the disciplinary approach to science teaching advocated by scientists in the 1960s, which they believed had touched only a narrow slice of privileged, college-bound students and had failed to meet the educational needs of the majority. (DeBoer 1991; Moore 2008).

Immersing students in the pressing technological and societal issues of the day, such as world hunger, population growth, water resources, and energy shortages was not a novel approach to science teaching. Dubbed "Science Technology and Society" (STS), it had a long tradition that, although overshadowed by the disciplinary turn taken by scientists in the 1960s, had remained of interest to science educators throughout the twentieth century. In

1958, Stanford education professor Paul DeHart Hurd, a leading advocate of the STS approach, argued for a science education that would promote understanding science in its social and political context, a goal that came to be widely known as "scientific literacy." The idea of literacy, then and now, is highly ambiguous, and it clearly meant different things to the various science and educational interest groups with a stake in science education during this time. Like an empty vessel, everyone poured their understanding of what science education should be into their understanding of "scientific literacy." For most, in fact, the term continued to carry with it connotations of specialized knowledge (DeBoer 1991).

The phrase "scientific literacy" had gone largely unnoticed for years in the pages of education journals for most of the 1960s. In the 1970s, however, it gained notoriety as a powerful slogan that aimed to capture Hurd's notion of understanding of science in which interest and the real-world functionality of an individual's scientific knowledge were of primary importance. In 1971, the National Science Teachers Association (NSTA), the leading professional organization of high school science teachers (established in 1944), identified scientific literacy as the number one goal of science education. Their focus on relating science to everyday life was, in part, a reaction against scientists' insistence on building student understanding of disciplinary knowledge and process in the context of scientific research, which was the predominant learning goal of the curriculum projects brought to market a decade earlier. The new focus on scientific literacy harkened back to science education's progressive roots. Through a variety of curricular projects and concerted public advocacy, classroom science teachers and university education professors succeeded in shifting the focus of science education away from scientists and the discipline-centered large-scale reforms of the 1960s and toward science education for personal and social needs.

The most explicit efforts to reformulate science education in the 1970s could be seen in the multiple attempts to develop STS content for science classrooms. The teaching units developed during this period were smaller and less ambitious in some ways than the richly funded material from the NSF era. And, although advocates of STS education tended to agree on the overarching goals of science education, their approaches varied. In general, they agreed that science education should take a "humanistic approach" in which the material taught would enable students to make connections between science and the wide range of human endeavor. Similarly, the method of science teaching shifted as well, from immersing students in cutting-edge laboratory activities toward instruction that promoted student-choice and decision-making with the ultimate goal being social action (often related to solving environmental problems). Some educators argued for a more explicit incorporation of personal and social values into science education. In those classrooms, students would be presented with a dilemma and asked to work through a solution on their own. This approach lent itself to argumentation, disagreement, and discussion, and the goal was a type of engagement that would promote social consciousness and a willingness to make changes in the world.

By the close of the 1970s, one could find a mix of approaches to science education—science teaching was, at times, structured around social issues and, at other times, the primacy of the disciplines was maintained, with an emphasis on the mastery of science content first and concern with social application deferred. Yet despite these differences, most science educators agreed that science needed to be presented within its social and cultural context. Educators on both sides of the debate were keen to place the emphasis back on student needs by framing subject matter through pressing social issues. They would soon encounter, however, the political realities of the 1980s when a new group of policymakers urged that science education be viewed, once again, as a way to advance national interests—this time, however, interest centered on the American economy rather than national security.

Inquiry and the Standards Movement

A renewed wave of attention to science education rippled through the country following the 1983 release of the Reagan administration's Commission on Educational Excellence report *A Nation at Risk*. Echoing the public clamor for science education reform following the launch of Sputnik, the report insisted on greater attention to academic subject matter in order to compete with the Japanese economic juggernaut. This set off a new round of reform initiatives and ushered in the educational standards era in the United States. The report complained that the United States educational system had spent the previous decade on the sidelines and had "squandered the gains in student achievement made in the wake of the Sputnik challenge." Yet, unlike during the height of the cold war, the stakes this time revolved around economic concerns. "Our once unchallenged preeminence in commerce, industry, science, and technological innovation," the report opened, "is being overtaken by competitors throughout the world." The Commission argued that this was a systemic failing and blamed politicians and educators alike who had "lost sight of the basic purposes of schooling, and of the high expectations and disciplined effort needed to attain them." (National Commission on Excellence in Education 1983).

The response from the professional community, made up of educators and scientists alike, was to draft several policy documents that would define the scope of a basic science education for all citizens. In the late 1980s, the American Association for the Advancement of Science (AAAS), the leading professional science society in the country, initiated *Project 2061,* an operation dedicated to generating a vision and blueprint for science education reform in the United States. Recognizing the difficult challenge before them, they set the year 2061 (when Halley's comet would return to the Earth's sky) as their target date. In 1989 they released a manifesto describing what the general public should know about science, *Science for All Americans.* Three years later, NSTA put out its own set of standards, *Scope, Sequence, and Coordination of Secondary School Science,* which was itself followed by the more detailed, age-graded version of the AAAS standards, *Benchmarks for Science Literacy* (1993). The presence of competing standards documents was a point of concern among policymakers and science education advocates, which prompted the National Research Council (NRC)(the working arm of National Academy of Sciences, a long-standing quasi-governmental science advisory agency) to step in and lay out the *National Science Education Standards* in 1996. In this work, the NRC largely endorsed the work of the AAAS, effectively consigning the NSTA curricular guidelines to a work of small influence (Collins 1998).

Both the NRC and the AAAS documents overlooked much of the science education work of the 1970s. Instead, they drew heavily from the disciplinary approach pursued in the 1960s. (The primary architect of AAAS's *Project 2061,* in fact, was F. James Rutherford, one of the key figures in the development of Harvard Project Physics years earlier.) Two central themes explicitly framed the science curriculum put forth within these texts: inquiry and the nature of science. The inclusion of inquiry reprised the focus on inquiry that was central to the post-Sputnik curriculum reform projects. The meaning of inquiry in the new standards documents, however, had shifted—the term now referred primarily to a method of instruction involving student, hands-on engagement with science projects or activities. Left behind were the more fundamental learning goals related to student understanding of scientific inquiry as it operated within disciplinary contexts.

Complementing this emphasis on inquiry in these standards documents was a focus on student understanding of the nature of science, a key learning goal that had emerged during the early days of the standards era (the early 1980s) partly in response to the conservative push for teaching creation science alongside evolution in the schools. (This was yet another skirmish in the ongoing debates over evolution in the schools) (Numbers 2006). Many believed that understanding the nature of science—elements of which included knowing that science depends on empirical evidence, is subject to change as new evidence comes to light, and so on—would provide students with the skills to identify science from non-science and ensure that topics like creationism would be clearly seen as "unscientific". Inquiry and the nature of science, many hoped, would work in concert in the curriculum, with students engaging and participating in science through inquiry, and inquiry activities undergirding and providing lessons on the nature of science and the process of knowledge production.

These documents, the *Benchmarks for Scientific Literacy* in particular, did much to shape the content and sequence of high school science programs during the 1990s and 2000s. Local school districts and state education departments worked to match their curricula and classroom instruction with the prescriptions laid out in these texts. They arguably had even greater impact on the content of science textbooks. Not long after the ink was dry on the standards, publishers leapt to adjust their books and tout their alignment with the national science standards as a key marketing strategy.

Standards, Testing, and Global Competition

By the mid-1990s, science education was increasingly driven by concerns over quality and accountability, which were viewed through the lens of student performance on standardized tests. Mediocre student performance on a series of international science and math assessments in the 1980s, highlighted in the *Nation at Risk* report, led to a government push for far-reaching accountability systems. In the late 1980s, the White House and the National Governor's Association approved the *Goals 2000* initiative, which called for U.S. students to be first in the world in science and mathematics achievement by the year 2000. A few years later in 1993, the National Science Board, an independent, presidentially appointed advisory body representing the United States science and engineering community, began tracking the low state of public understanding of science using a fact-based metric in its biannual *National Science and Engineering Indicators* reports.

These surveys consistently found appalling low levels of public understanding of basic science content and scientific process. Continued poor performance by U.S. students on tests at a variety of levels from the international *Trends in International Mathematics and Science Study* (TIMSS) and the *Programme for International Student Assessment* (PISA) as well as domestic assessments such as those done as part of the *National Science and Engineering Indicators* throughout the 1990s and 2000s provided ammunition to critics who argued for greater emphasis on science and mathematics in the name of global economic competition. The result of all these measures was, not surprisingly, a greater focus on science content knowledge in schools and more testing to ensure its mastery (Fuhrman 2003; Toch 1991; Vinovskis 2008).

By the turn of the twenty-first century, educational accountability was a national issue. Passage of the No Child Left Behind Act (NCLB) in 2001 required that all school districts demonstrate annual yearly progress (AYP) in student standardized test scores across multiple student groupings in a common set of academic subjects. The first years of the law required achievement gains only in mathematics and reading, reducing subjects like science and social studies to the margins. (It remains too early to tell how more recent testing in science [started in 2007, but not included in calculations of AYP] will affect the amount of time devoted to teaching that subject.) Classroom experiences of children have, not surprisingly, reflected this new emphasis on testing and accountability. Many educators and parents have bemoaned the rote learning taking place in classrooms, while others have applauded the ability of these tests to transform pedagogy. Much of the concern over curricular narrowing—the result of teachers focusing instruction on material likely to appear on the exams—has been limited to the pre-high school grade levels where concerted efforts have been made to improve student test performance to avoid the legislative sanctions that result from failure to make AYP.

At the high school level, the prevailing emphasis on accountability has combined with the neo-liberal emphasis on education as a private good to push greater adoption of Advanced Placement (AP) course offerings in academic subjects, particularly the sciences. While poor districts have been measured by NCLB results, wealthy suburban schools districts have increasingly measured their success—and sold the strength of their high schools—by how many AP courses are available to students and how well their students perform on the corresponding AP exams, with high scores enabling students to secure college credit for the subject in question. The AP course curricula and tests, in their aim to mirror introductory, college-level courses, focus heavily on mastery of disciplinary content rather than on scientific process or epistemology. The increased attention on standardized test performance at all levels and across all schools—from elementary through high school and from poor to wealthy districts—has pushed student performance toward fact-based, content-focused learning outcomes. While this emphasis has aligned somewhat with the science concepts and knowledge included in the various national standards documents, it has also marginalized efforts—equally present in the standards—to have students learn about the relationship between science and cultural issues, learning goals that were more prominent in the 1970s (Sadler, et al. 2010).

The urgency and pace of reform has picked up noticeably since the turn of the most recent century with a renewed emphasis on scientific and technical workforce issues. Pulitzer prize-winning journalist Thomas Friedman's popular book, *The World is Flat,* published in 2005, reignited national concerns over global competition in science and technology, which led to another National Academy of Sciences report two years later, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (2007). This report coincided with the passage of the America Competes Act that same year, legislation that many have described as a modern-day equivalent of the 1958 National Defense Education Act, which included among its many provisions federal support for science and math-focused teacher certification programs at the graduate and undergraduate levels, programs to expand student and teacher participation in Advanced Placement programs, and greater dissemination of promising science and math teaching practices at the pre-college level. Yet another call for more attention to science and mathematics education has been made by the Carnegie-Institute for Advanced Study Commission 2009 policy statement, *The Opportunity Equation: Mobilizing for Excellence and Equity in Mathematics and Science Education.* This report, as well as others, calls for a smaller set of common science standards that could be used as a guiding framework by all states and that would apply across all the relevant science, technology, engineering, and mathematics disciplines. The first step toward realizing this goal was the NRC publication of *A Framework for K-12 Science Concepts and Core Ideas: Practices, Crosscutting Concepts, and Core Ideas* in 2011.

This flurry of reports and government action since 2005 have set off a new sense of crisis similar to that of the 1980s, but this time with countries like India and China taking Japan's place as the global economic threat to American prosperity. An overriding concern with scientific capacity and technological innovation has clearly taken hold as the predominant motivation for national investment in science education, especially in the high schools. In many ways, this focus on the vocational and utilitarian aims of science teaching echoes the original utilitarian justifications for teaching science in schools made in the middle 1800s. The main difference between then and now, however, lies in the shift in emphasis on our public justification for science teaching in the high school. In the era prior to World War II, the study of science in schools was viewed as something with a tangible benefit to students and citizens, be it moral, cultural, or practical. Current arguments cast the value of science education in terms of national security and global competitiveness, and the state and private interests have increasingly developed the social and administrative machinery to turn science classrooms toward such ends.

REFERENCES

Ahlstrom, S.E. 1972. *A Religious History of the American People.* New Haven: Yale University Press.

American Association for the Advancement of Science. 1989. *Science for All Americans.* Washington, D.C.

American Association for the Advancement of Science. 1993. *Benchmarks for Scientific Literacy.* New York. Oxford University Press.

Atkin, J.M. and Black, P. 2003. *A History of Curricular and Policy Change.* New York: Teachers College Press.

Benson, K.R. 1988. "From Museum Research to Laboratory Research: The Transformation of Natural History into Academic Biology." In *The American Development of Biology* edited by Ronald Rainger, Keith R. Benson, and Jane Maienschein, 49-83. Philadelphia: University of Pennsylvania Press.

Carnegie Corporation of New York and Institute for Advanced Study Commission on Mathematics and Science Education. 2009. *The Opportunity Equation: Mobilizing for Excellence and Equity in Mathematics and Science Education for Citizenship and the Global Economy.* New York: Carnegie Corporation of New York.

Collins, A. 1998. "National Science Education Standards: A Political Document." *Journal of Research in Science Teaching,* 35: 711-727.

Committee on Science, Engineering, and Public Policy. 2006. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* Washington, DC: National Academies Press.

Committee of Ten. 1894. *Report of the Committee of Ten on secondary school studies.* Washington, DC: National Education Association of the United States.

Conn, S. 1998. *Museums and American Intellectual Life, 1876-1926.* Chicago: University of Chicago Press.
Cotter, D. 2008. "A disciplinary immigrant. Alexander Smith at the University of Chicago, 1894 1911." *Annals of Science* 65(2): 221-256.

Clowse, B. 1981. *Brainpower for the Cold War: The Sputnik crisis and National Defense Education Act of 1958.* Westport, CT: Greenwood Press.

DeBoer, G. 1991. *A History of Ideas in Science Education: Implications for Practice.* New York: Teachers College Press.

Dow, P. 1991. *Schoolhouse Politics: Lessons from the Sputnik Era.* Cambridge: Harvard University Press.

Fuhrman, S. 2003. "Riding waves, trading horses. The twenty-year effort to reform education." In *A Nation Reformed? American Education 20 Years after A Nation At Risk*, edited by D.T. Gordon, 7-22. Cambridge: Harvard Education Press.

Geiger, R.L. 1986. *To Advance Knowledge: The Growth of American Research Universities, 1900-1940*. New York: Oxford University Press.

Geiger, R. 1998. "The Rise and Fall of Useful Knowledge: Higher Education for Science, Agriculture, and the Mechanic Arts." *History of Higher Education Annual* 18:47–65.

Guralnik, S. M. 1975. *Science and the ante-bellum American College*. Philadelphia, PA: American Philosophical Society.

Heffron, J.M. 1995. "The knowledge most worth having: Otis W. Caldwell (1869–1947) and the rise of the general science course." Science & Education 4(3): 227-252.
Higham, J. 1979. "The Matrix of Specialization," in *Organization of Knowledge in Modern America, 1860– 1920* edited by Alexandra Oleson and John Voss, 3–18. Baltimore: Johns Hopkins Press.

Hoffman, M. 2011. "Learning in the Laboratory: The Introduction of 'Practical' Science Teaching in Ontario's High Schools in the 1880s." In *Learning by Doing: Experiments and Instruments in the History of Science Teaching,* edited by P. Heering and R. Wittje, 177-205. Stuttgart: Franz Steiner Verlag.

Hollinger, D. A. 1984. Inquiry and uplift: Late nineteenth-century American academics and the moral efficacy of scientific practice. Bloomington: Indiana University Press.

Hollinger, D. A. 1990. "Free enterprise and free inquiry: The Emergence of Laissez-Faire Communiarianism in the Ideology of Science in the United States." *New Literary History* 21: 897–919.

Kaestle, C. 2001. "Federal Aid to Education Since World War II: Purposes and Politics." In *The Future of the Federal Role in Elementary and Secondary Education* edited by Jack Jennings, 13-39. Washington, D.C.: Center for Education Policy.

Kaestle, C.F. and Smith, M.S. 1982. "The Federal Role in Elementary and Secondary Education, 1940-1980." *Harvard Education Review* 52(4): 384-408.

Kelves, D.J. 2001. "Principles, Property Rights, and Profits: Historical Reflections on University/Industry Tensions." *Accountability in Research* 8: 12-26.

Keeney, E. 1992. *The Botanizers: Amateur Scientists in Nineteenth-Century America*. Chapel Hill: University of North Carolina Press.

Kleinmann, D.J. 1995. *Politics on the Endless Frontier: Postwar Research Policy in the United States.* Durham: Duke University Press.

Kliebard, H.M. 2004. *The Struggle for the American Curriculum, 1893-1958.* Third Edition. New York: Routledge Falmer

Klopfenstein, K. and Thomas, M.K. 2010. "Advanced Placement Participation: Evaluating the policies of states and colleges." In *AP: A Critical Examination of the Advanced Placement Program,* edited by Philip M. Sadler, Gerhard Sonnert, Robert H. Tai, and Kristin Klopfenstein, 167-188. Cambridge: Harvard Education Press.

Kohler, R.E. 1996. "The Ph.D. Machine: Building on the Collegiate Base." In *The Scientific Enterprise in America: Readings from Isis,* edited by Ronald L. Numbers and Charles E.
Rosenberg, 98–122. Chicago: University of Chicago Press.

Kohlstedt S.G. 2010. *Teaching Children Science: Hands-On Nature Study in North America, 1890-1930.* Chicago: University of Chicago Press.

Kremer, R. L. 2011. "Reforming American Physics Pedagogy in the 1880s: Introducing 'Learning by Doing' via Student Laboratory Exercises." In *Learning by Doing: Experiments and Instruments in the History of Science Teaching,* edited by P. Heering and R. Wittje, 243-280. Stuttgart: Franz Steiner Verlag.

Krighbaum H. and Rawson, H. 1969. *An Investment in Knowledge: The First Dozen Years of the National Foundation's Summer Institutes Programs to Improve Secondary School Science and Mathematics Teaching 1954-1965.* New York: New York University Press.

Krug, E. A. 1969. *The Shaping of the American High School, 1880-1920.* Madison: University of Wisconsin Press.

Larson, E. J. 2003. *Trial and Error: The American Controversy over Creation and Evolution,* Third Ed. New York: Oxford University Press.

Labaree, D.F. 1988. The making of an American high school: The credentials market and the Central High School of Philadelphia, 1838-1939. New Haven: Yale University Press.

Lacy, T. 2010 . "Examining AP: Access, rigor, and revenue in the history of the Advanced Placement program." In *AP: A Critical Examination of the Advanced Placement Program*
edited by Philip M. Sadler, Gerhard Sonnert, Robert H. Tai, and Kristin Klopfenstein, 17-48. Cambridge: Harvard Education Press.

Ladouceur, R.P. 2008. "Ella Thea Smith and the Lost History of American High School Biology Textbooks." *Journal of the History of Biology* 41(3): 435-471.

Larson, E.L. 1997. *Summer for the Gods: The Scopes Trial and America's Continuing Debate over Science and Religion*. New York: Basic Books.

Mann, C. R. 1909. "Physics Teaching in the Secondary Schools of America." *Science*, n. s., vol. 30, no. 779, 789-798.

Marsden, G.M. 2006. *Fundamentalism and American Culture.* New York: Oxford University Press.

Milam, E. L. In press. "The Paragon of Animals: Negotiating Human Nature with Man: A Course of Study." *History of Education Quarterly.*

Moore, K. 2008. *Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975.* Princeton: Princeton University Press.

Moyer, A.E. 1976. "Edwin Hall and the Emergence of the Laboratory in Teaching Physics." *Physics Teacher* 14(2): 96–103.

National Commission on Excellence in Education. 1983. *A Nation at Risk: The Imperative for Educational Reform.* Washington, D.C.: Government Printing Office.

National Education Association. 1918. *Cardinal Principles of Secondary Education.* Washington, D.C.: U.S. Government Printing Office.

National Education Association. 1920. Reorganization of science in secondary schools: A report of the commission on the reorganization of secondary education. Washington, D.C.: U.S. Government Printing Office.

National Research Council. 2011. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academies Press.

Numbers, R. L. 2006. *The Creationists: From Scientific Creationism to Intelligent Design.* Expanded Edition. Cambridge: Harvard University Press.

Numbers, R.L. 1998. *Darwinism Comes to America.* Cambridge: Harvard University Press.

Olesko, K.M. 1995. "German Models, American Ways: The 'New Movement' among American Physics Teachers, 1905–1909." In *German Influences on Education in the United States to 1917* edited by Henry Geitz, Jurgen Heideking, and Jurgen Herbst, 129–153. New York: Cambridge University Press.

Ogren, C.A. 1995. "Where Coeds Were Coeducated: Normal schools in Wisconsin, 1870-1920." *History of Education Quarterly* 35(1): 1-26.

Ogren, C.A. 2005. *The American State Normal School: An Instrument of Great Good.* New York: Palgrave Macmillan.

Owens, L. 1985. "Pure and sound government: Laboratories, playing fields, and gymnasia in the nineteenth-century search for order." *Isis* 76(2): 182-194.

Patterson, J.T. 2001. *Brown V. Board of Education: A Civil Rights Milestone and Its Troubled Legacy.* New York: Oxford University Press.

Pauly, P.J. 1991. "Development of High School Biology: New York City, 1900-1925." *Isis*, 82(4): 662-688.

Pauly, P.J. 2000. *Biologists and the Promise of American Life: From Meriwether Lewis to Alfred Kinsey.* Princeton: Princeton University Press.

Purcell, E. A. 1973. *The Crisis of Democratic Theory: Scientific Naturalism and the Problem of Value.* Lexington: University Press of Kentucky.

Ravitch, D. and Vinovskis, M. 1995. *Learning from the Past: What History Teaches Us about School Reform.* Baltimore: Johns Hopkins Press.

Reese, W. J. 1995. *The Origins of the American High School.* New Haven: Yale University Press.

Reese, W.J. 2011. *America's Public Schools: From the Common School to 'No Child Left Behind.* Baltimore: Johns Hopkins Press.

Rosen, S. 1954. "A History of the Physics Laboratory in the American Public High School (to 1910)." *American Journal of Physics* 22: 200.

Ross, D. 1992. *The Origins of American Social Science.* New York: Cambridge University Press.

Ruben, J.A. 1996. *The Making of the Modern University: Intellectual Transformation and the Marginalization of morality.* Chicago: University of Chicago Press.

Rudolph, J.L. 2002a. *Scientists in the Classroom: The Cold War Reconstruction of American Science Education.* New York: Palgrave Macmillan.

Rudolph, J. L. 2002b. "From World War to Woods Hole: The Use of Wartime Research Models for Curriculum Reform." *Teachers College Record* 104, 212-241.

Rudolph, J.L. 2005a. "Epistemology for the Masses: The Origins of 'The Scientific Method' in American Schools." *History of Education Quarterly* 45(3): 341-376.

Rudolph, J.L. 2005b. "Turning Science to Account: Chicago and the General Science Movement in Secondary Education, 1905-1920." *Isis* 96(3): 353-389.

Rudolph, J.L. 2005c. "Inquiry, Instrumentalism, and the Public Understanding of Science." *Science Education* 89(5): 803-821.

Rudolph, J.L. 2012."Teaching Materials and the Fate of Dynamic Biology in American Classrooms after Sputnik." *Technology & Culture* 53: 1-36.

Sadler, P. M., Sonnert, G., Tai, R. H., and Klopfenstein, K., Eds. 2010. *AP: A Critical Examination of the Advanced Placement Program.* Cambridge: Harvard Education Press.

Schulten, S. 2001. *The Geographical Imagination in America, 1880-1950.* Chicago: University of Chicago Press.

Shapiro, A.R. 2008. "Civic Biology and the Origin of the School Antievolution Movement." *Journal of the History of Biology* 41(3): 409-433.

Skoog, G. 1979. "Topic of evolution in secondary school biology textbooks, 1900-1977." *Science Education* 63(5): 621–640.

Slotten, H.R. 1991. "Science, Education, and Antebellum Reform: The Case of Alexander Dallas Bache." *History of Education Quarterly* 31(3): 323– 342.

Smuts, A.B. 2006. *Science in the Service of Children, 1893-1935.* New Haven: Yale University Press.

Tobey, R.C. 1981. *Saving the Prairies: The Life Cycle of the Founding School of American Plant Ecology, 1895-1955.* Berkeley: University of California Press.

Toch, T. 1991. *In the Name of Excellence: The Struggle to Reform the Nation's Schools, Why It's Failing, and What Should Be Done.* New York: Oxford University Press.

Tolley, K. 2002. *The Science Education of American Girls: A Historical Perspective.* New York: Routledge Falmer.

Tolley, K. 2001. "The Rise of the Academies: Continuity or Change?" *History of Education Quarterly* 41(2): 225–239.

Turner, S.C. 2011. "Changing Images of the Inclined Plane: A Case Study of a Revolution in American Science Education." In *Learning by Doing: Experiments and Instruments in the History of Science Teaching,* edited by P. Heering and R. Wittje, 207-242. Stuttgart: Franz Steiner Verlag.

Tyack, D.B. and Cuban, L. 1995. *Tinkering toward Utopia: A Century of Public School Reform.* Cambridge: Harvard University Press.

Tyack, D.B., & Hansot, E. 1982. *Managers of Virtue: Public School Leadership in America 1820-1980.* New York: Basic Books, Inc.

Urban, W.J. 2010. *More than Science and Sputnik: The National Defense Education Act of 1958.* Tuscaloosa: University of Alabama Press.

Vettel, E.J. 2006. *Biotech: The Countercultural Origins of an Industry*. Philadelphia: University of Pennsylvania Press.

Veysey, L.R. 1970. *The Emergence of the American University*. Chicago: University of Chicago Press.

Vinovskis, M. 2008. *From a Nation at Risk to No Child Left Behind: National Education Goals and the Creation of Federal Education Policy*. New York: Teachers College Press.

Zimmerman, J. 1999. *Distilling Democracy: Alcohol Education in America's Public Schools, 1880-1925*. Lawrence: University Press of Kansas.