THE EMERGENCE OF THE LABORATORY METHOD & THE DISPLACEMENT OF NATURAL PHILOSOPHY BY PHYSICS IN AMERICAN HIGH SCHOOL TEXTBOOKS (1860-1900).

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ABSTRACT

Advocating for the laboratory method was a distinguishing feature of textbooks as *physics* displaced *natural philosophy* in American schools during the second half of the nineteenth century as the dominant tradition of teaching physical science. This dissertation examines digital editions of textbooks in common use during the period to tell the narrative of this emergence and transformation. I contend that the transformation from the tradition of *natural philosophy* to that of *physics* succeeded less because of the agency of individual actors, but because schools were responding to the perceived needs and changing realities of their societies. Understanding the how this transformation occurred, however, requires examining the contributions made by individual actors. Teachers frequently look to textbooks for guidance, even if they do not follow them entirely. This dissertation examines the changing series of textbooks published during the period from the middle of the 19th century to its end, and compares the instructions given to teachers in the introductory sections to trace the evolution of physical science instruction over time. The significance of this dissertation lies in its contribution to our evolving understanding of science education and what leads to educational change.

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CHAPTER 1. INTRODUCTION -- SETTING THE STAGE

This dissertation examines how the tradition of *Physics* with its greater emphasis on laboratory work and direct student investigations, emerged from its predecessor *Natural Philosophy* in America's high schools in the late 19^{th} century. The late 19th and early 20th centuries saw a vast expansion of industry, urban growth and technological advances. This was the age during which electric lights replaced gas lighting, telephones and radio replaced telegraphs, and electric generators and internal combustion engines replaced steam as the primary driving force of industry. As the effects of this second industrial revolution pushed deeper into American daily life, and both urbanization and factory employment climbed, so, too, did the perceived need for everyday Americans to have a greater understanding of science.

Schools, as has often happened, were identified as a primary site where such social change could be instilled. Government officials, scientific professional organizations and science teachers in the 1880s began to assert the importance of changing the way science was taught in order to bring the ideals of the *Scientific Revolution* into America's classrooms. As the time period in which the events of this dissertation played out was also a period of hegemony by white heterosexual males, and this dissertation looks primarily at the voices at the center of the discussion, I freely acknowledge the bias of both sources and narrative towards that group as they were most commonly published. I can only hope another scholar, with a better and deeper understanding of minority groups, will be able to tell the story of those not found here.

This chapter provides a framework and contextual background to guide the reader forward. In this chapter italics are used to identify key terms, later in the work the italics are dropped for the purpose of readability. For the sake of clarity, some of these terms are defined here at the outset. *Physics* is today a widely taught high school science course which emphasizes laboratory work by students and is the dominant means by which the subject of physical science is taught to students. This was not always the case; prior to the 1880s most American high school students would have learned about similar topics but known their course as *natural philosophy.* The difference between *physics* and *natural philosophy* went deeper than the title; a central argument proposed in this dissertation is that *natural philosophy,* which was the title of numerous physical science textbooks prior to 1880, belonged to an entirely different instructional tradition than *physics*. The term *tradition* is used here to denote a set of practices with distinguishing characteristics familiar to and followed by practitioners of the instructional arts. The term *physical science* is used to refer not to any specific course or tradition, but rather to the general content covered (motion, heat, electricity and magnetism, light and sound) by both *natural philosophy* and *physics.*

To a large extent *physics* emerged from and displaced its predecessor as American society sought to modernize its curriculum in an effort to match the rapid changes in technology, work environment, and household economy. It can also be seen as resulting from efforts to bring the ideals of the *Scientific Revolution* into the classroom in order to make students active investigators and knowledge seekers. In the grand narrative of history Galileo Galilei (1564-1642), Francis Bacon (1561-1626), Rene Descartes (1597-1650) and other well-known figures of 16^{th} and 17^{th} century Europe changed the very way think about the natural world. Because they changed how many others thought about the physical world, they were known as *natural* *philosophers* meaning lovers of wisdom regarding nature. However, more of their fame today rests on *how* they approached knowledge concerning the natural world, rather than the details of *what* they said about it. These leading lights are credited with is developing a new approach, or method, to learning about nature; they emphasized direct experience and first-hand investigations into nature's mysteries rather than relying on the accumulated knowledge of others. This intellectual movement, which we know as the *Scientific Revolution* occurred between the 15^{th} and 17^{th} centuries (Boas, 1962), yet until the last few decades of the 19th century very little of this investigative spirit made it into the American classroom.

Well into the 1870s *Natural Philosophy* was a common high school course and the dominant tradition of teaching physical science. An examination of textbook titles from this period shows that most bore *Natural Philosophy* as the title, and that of *Physics* was rarely seen (c.f. master bibliography by Meltzer & Otero, n.d.). It placed the emphasis on rote mastery of the accumulated body of scientific knowledge as possible, rather than practicing its methods. Students studied definitions rather than phenomena and learned largely from textbooks before regurgitating information during recitations. Instead of performing their own investigations, students watched as a few physical principles were demonstrated before them, if they were lucky enough to have a gifted teacher. Laboratory equipment was expensive and showy before the emergence of physics, designed not for the student but for class wide demonstration. Such equipment spent most of the school year safely locked in a cabinet. The method of instruction was not different from what one might find in a history class. Indeed, given the insistence of later authors regarding the importance of incorporating a space especially designed for laboratory work, many of the classrooms used to teach natural philosophy likely were indistinguishable from those in which literature, math or Latin was studied, lacking any suitable place for experimentations (Chute, 1889; Smith & Hall, 1902). Instruction of this sort grew out of a conception of science as a branch of speculative philosophy with debates tracing back to the classical Greeks; it was the very form of learning Francis Bacon and others railed against the sterile, making *natural philosophy* as taught in mid-nineteenth century American schools antithetical to the spirit of the Scientific Revolution.

It was only towards the end of the 19th century, as more professional men of science turned their attention to America's classrooms that science instruction began to transform into something mirroring the work of scientists. A key feature of the new *physics* was the central place student laboratory work took in what was known as the *laboratory method*. Rather than emphasizing the rote learning of content, *physics* sought to teach students the method and skills of an investigator, and so learn the ways of science. The laboratory method, which called for student work conducting laboratory experiments, was considered the ideal means to bring about this shift in attitude needed to improve science education (Clarke, 1880; AAAS, 1881; Gage, 1882; Wead, 1884; Chute, 1889; Smith & Hall, 1902). In part the new tradition of high school physics resulted from an increasing demand for more mechanically literate workers to maintain and improve the industries which were becoming the backbone of the American economy. In part it also resulted from the expansion of laboratory work at the college level and an increase in the number of academics with a taste for teaching experimental physics. Before working its way down and becoming a growing expectation for the high school curriculum, experimental physics emerged at the college level.

There considerable variance among scholars at to when the transformation occurred at the college level. Frank W. Clarke, writing during our period of interest, found "a new period in American science began" between 1845 and 1850 as, "scientific schools were established at

Harvard and Yale; the Smithsonian Institution commenced operations; [and] the American Association for the Advancement of Science was organized" (1880, p. 13). Rudolph and Meshoulam (2014, p. 4) found that "laboratory instruction as a means of general education, or liberal study, however, came only after the incorporation of teaching laboratories in the larger universities and liberal arts colleges" work which was begun at Harvard in the 1850s and 1860s. Meltzer and Otero (2015, p. 447) date the origins of physics education in America to the period between 1860 and 1884, for only then did physics gain, "a firm foothold in college curricula after long resistance by proponents of 'classical' education" but this seems late as by the 1880s experimental physics had begun to catch on in the secondary schools.

Prior to the establishment of experimental physics, even at the college level physical science was taught as natural philosophy and prized for its valuable practical, factual knowledge (Kremer, 2011). The impetus to incorporate laboratory work has generally been seen as having a German origin (Clarke, 1880; Olesko, 1995; Rosen, 1953; Rudolph and Meshoulam, 2014). The explanation is that Americans who studied abroad brought back the German ideal of science seminars with "their commitment to obligatory practical exercises in precision measurements" which were "designed to aid the understanding of introductory material, and... achieve the pedagogical consolidation of disciplinary knowledge" (Olesko, 1995, p. 133). Kremer (2011) however has argued, based on a case study of Dartmouth College, that Pickering's textbook (1873-1876) had more to with the adoption of the laboratory method than any German influence. Once *Physics* was accepted into the college curriculum a struggle over how physical science ought to be taught at the secondary level ensued, becoming one of the enduring theme in the history of physics education (Meltzer & Otero, 2015). As more was demanded at the post-secondary level, more became expected from the high school.

While this dissertation focuses on physics and the laboratory method, it must be pointed out that events in Chemistry influenced those in physics. Alfred Gage, in 1882, noted that the laboratory method had already been adopted in Chemistry, and with great success, during the preceding twenty years. Edwin Hall, who has been credited by Rosen (1953) and others with having a substantial role in establishing the new physics tradition, wrote that “Chemists were more influential than physicists in framing the new science requirements” (Smith & Hall, 1902, p. 271). This comment was aimed at what became apparent in the 1890s as an over-emphasis on laboratory work to the point of excluding lectures and book-work. As physics evolved into a well-balanced tradition that drew on laboratory work but also other means of instruction, Hall sought to distance himself from his early association with excessive laboratory work. Hall’s mature thoughts on teaching, compiled in *The Teaching of Chemistry and Physics in Secondary Schools*, which he co-authored with Alexander Smith, parallels the maturation of the tradition itself as well as the continued interplay between the two branches of physical science.

To summarize, this dissertation traces the emergence of the laboratory method and the American tradition of physics instruction during the 1880s. The ideals of the Scientific Revolution, which emerged in the 16th and 17th century and sought to revolutionize the humanity’s thinking regarding its interaction with the physical universe, had by the middle of the 19th century still not revolutionized learning in American science classrooms. The Scientific Revolution had promoted the ideal that knowledge is to be found through personal investigations, and while the work of past scholars might be helpful, a blind acceptance of it must never get in the way of one’s own search for truth; scientists must approach received knowledge and even their own understanding with skepticism, looking for ways to test its validity. When one examines the textbooks published for use in America’s academies, high schools and common schools in the 1860s, one finds the subject natural philosophy taught largely as a literary matter, focused on committing the accepted axioms and definitions to rote memory. While new content had entered into the textbooks, the way of learning remained that of reading and reciting lessons. There was little emphasis on students investigating nature and the term laboratory was mentioned only with regard to the work of grown-ups if at all. In more sophisticated terms the central epistemology, axiology and ontology of instruction reflected more the mindset of medieval Europe rather than that engendered by the Renaissance, Scientific Revolution, and Enlightenment. In less sophisticated terms it was as if the Scientific Revolution and its essential defining outlook had never occurred.

Scope of Study

In this section I lay out the scope of the study. It begins with an account of my point of departure and what I thought my dissertation would about when I began researching the topic and the period. I then discuss my research questions, before giving a brief overview of what I refer to as *the laboratory method,* a term used by two 19th Century textbook authors (Carhart and Chute, 1892) to describe what they saw as becoming a common practice. This is followed by a short discussion of the history of science education and our current notions of what science education is and should be, which is then tie this back to where these ideals came from, namely the scientific revolution. My purpose in doing so is to provide the reader with a sketch of the landscape.

Initial Conception

When I initially began researching this topic, I imagined I would center my narrative around what happened between the Report of the Committee of Ten and the Cardinal Principles of Secondary Education. My intent was to document the events that led to such a profound shift in perspective in such few years. My interest in this fascinating period came from the work of other historians. George DeBoer (1991) made it appear that it was the work of the Committee of Ten which launched physics education as we know it. The report of that Committee also featured heavily in other works such as that of Cremin (1961), Sizer (1964), Kliebard (1995) which all took it as a jumping off point for the emergence of something new. The Cardinal Principles on the other hand were described as demarcating a reversal of fortunes and a new direction for education (including science). As Kliebard wrote, “So widely accepted were Kingsley’s recommendations that 1918 may be regarded as the year when the humanist position reflected in Eliot’s Committee of Ten report was forced to go on the defensive” (1995, p. 99).

And then, reading a recent author regarding the historiography of education I came to question if I was not covering too familiar ground (Gaither, 2013). Gaither’s work planted the seed that perhaps too many historians focusing on events right around the turn of the century and afterwards and more room existed for fresh, fruitful work somewhat further in the past. While I did not immediately shift my focus, this work caused me to question it; it was when I got into the primary sources, the textbooks of the period, I began to realize how much of the shift towards laboratory work preceded the Report of the Committee of Ten in 1893. As my central interest was this emergence of the laboratory method, I realized beginning in 1893 was starting too late. This dissertation focuses on the emergence of *Physics* and the laboratory method as a teaching tradition distinct from that of *Natural Philosophy.* As such, it begins with examining popular textbooks used in American classrooms during the 1860s and continues to track the development in these primary sources through three decades into the 1890s.

By the early 1890s, the use of individual student laboratory work had become taken as a hallmark of quality science instruction, as witnessed by the recommendations of the conference on Physics, Chemistry and Astronomy to the Committee of Ten in 1892. The period from 1890 to 1920, often referred to as the “Progressive Era” in American history, saw similar progressivism in education and has received considerably more scholarly attention than the preceding decades (Cremin, 1961; Kliebard, 1995; DeBoer, 1991; Rury, 2002). While much of historical interest followed the publication of the Report by the Committee of Ten, this dissertation focuses on the events that led up that first attempt at standardizing the curriculum at a national level.

Evolving Research Questions

My research questions have their origins in my professional duties; they began with the concrete considerations a classroom science teacher faces on a daily basis. I spent six of the last nine years teaching high school science, and the other three serving as an instructional coach to both science and career & technical education teachers. Teaching physics most recently, I deliberated on how to plan and run effective labs, what content to emphasize, and what best practices (pedagogical strategies) to apply. As the complex array of options circulated through my mind, I began to wonder how others had done it in the past. My questions expanded outward from there in ever-widening circles. I wondered how the recommendations of content experts or specialists changed (or didn’t change) over time, how these changes matched (or didn’t match) those of general reformers or leaders in education, and ultimately, how all these attempts to improve classroom instruction might best be understood within the wider social context of a period. As an instructional coach my questions extended further to wonder how did our current concepts of what science should be come to be what they are? How do we improve science instruction and why have past efforts so often failed to achieve their intended aims? These questions came to me from my work experience in the public-school system, outside my academic research, and explain to a great extent what my stake is in this topic.

Under my initial conception of the project to examine the changes occurring between 1893 and 1918, my research questions were as follows:

1) What pedagogical practices pertaining to the laboratory were recommended in high school physics textbooks during the period from the publication of the *Report of the Committee of Ten* (1893), and the *Cardinal Principles of Secondary Education* (1918)
2) Did such practices change noticeably during this period?
3) If such changes can be identified, do they correspond in a meaningful way to the recommendations made by educational reformers of the period such as Charles Eliot, G. Stanley Hall, and others? Did authors of the physics textbooks, in other words, follow the recommendations of the reformers?
4) To what extent does situating these recommendations in light of the larger social contexts of the period aid in interpreting the described practices? Does the consideration of social context lead to greater understanding, clarity, or explanatory power?

5) Are there enduring lessons which resonate with contemporary discussions such as those surrounding the *Next Generation Science Standards*? (NGSS Lead States, 2013).

These were the questions put forth in my research proposal. As I realized that this time period was too late to address my fascination with the laboratory method, I found my research questions evolving. The more I examined the primary sources, especially the reports of Clarke (1880), the AAAS (1881) and Wead (1884), together with such textbooks as Alfred Gage (1882), Trowbridge (1884), Worthington (1886), and Chute's lab manual from (1889), the more I realized I needed to look to events before the Committee of Ten, rather than after. As I grappled with defining my central argument and developed a story-board (Turabian, 2013), the exciting and important story of how physics emerged from natural philosophy began to clarify itself.

Applying an inductivist approach (Saldana, 2015), I revised my research questions to better align with where my findings seemed to be headed, and they can now be summarized as follows. 1) How can the rising popularity of the laboratory method be understood? This was my central question, but certainly *not* the first question I asked. It arose as I queried both the sources and myself, searching for patterns, significance and meaning. It belies a familiarity with the topic, for one must already know the laboratory method existed and that for a time it gained popularity. 2) What do we already know about the history of physics teaching, and how can my research contribute to this understanding? This guided my background reading, helped guide me into the topic, and helped clarify what I hoped to accomplish. 3) What is the relationship between school and society, and how do school systems change? This was a fascinating, broader picture question leading into thinking about complex systems. It both forced and allowed me to expand my research beyond physics textbooks to understand the historical period in which the central events took place. 4) In what ways is the emergence of physics a reflection of the values implicit in the Scientific Revolution? This question got at the spirit of the scientific endeavor, called for historical comparisons, and justified looking at the purpose the authors held. 5) Finally, what makes the history of science education worth studying and how does it relate to our concerns today? As exciting as I found this investigation, most people want to know how or why it matters. This question enabled me to ponder the value of history and the defining importance of perspective and positionality, for the significance of history lies in how we interpret the facts, and in the narrative, we construct from them.

My sources fall into the usual two categories of primary and secondary, with primary sources being those written during the period of investigation based on personal experience, and secondary sources being those written based on some investigation of the primary record after the fact. For primary sources, I draw firstly upon textbooks published during the period and intended for use in secondary schools. Many of these are accessible online in digital copies via Google Play Books; they can also be accessed via the *Master Bibliography* by Meltzer and Otero. The collection of physics textbooks available digitally online is considerable and includes some series which ran through a number of editions and title changes over several decades (c.f., Carhart and Chute, 1897 to 1917; Gage, 1884 to 1902; Hall and Bergen, 1891 to 1912). Other primary sources, such as the reports of national committees (particularly the NEA publications of 1893, 1918, 1920) and the writings of contemporary educational leaders such as C.W. Eliot, and W.T. Harris, are used to gain a wider angle on how schools were perceived to be changing or needed to be changing. Secondary sources, often the work of professional historians or scholars, were used to triangulate my findings and interpretation of the primary sources.

The Laboratory Method

The American physics classroom was a rather unscientific place in the 1860s. Indeed, most of the textbooks for physical science bore another name: *Natural Philosophy*. This tradition, which held sway for most of the 19th century, relied heavily on textbooks as the primary source of knowledge and recitation as main instructional method (Norton 1870; Quackenbos, 1871; Steele, 1871; Peck, 1871; Reese 1995; Meltzer & Otero, 2015). Criticism of this tradition increased in the later decades of the 19th century (Clarke, 1880; AAAS, 1881, 1888; Wead, 1884; NEA 1887) as a distinct tradition of instruction emerged. Bearing the title of *Physics,* this new tradition championed the *laboratory method* as the ideal means of inculcating an understanding of the natural, inanimate world. Seen as approximating the actual work of scientists more closely and meaningfully, the laboratory method gained favor during the final three decades of the 19th century.

Professional groups and the Bureau of Education began sponsoring assessments of the general state of affairs in the methods used to teach physical science in America's schools (Clarke, 1880; AAAS, 1881, 1888; Wead, 1884; NEA 1887). The resulting reports, highly critical of the older *Natural Philosophy* tradition, ushered in a new wave of textbooks as authors picked up on the rising demand for books promoting more laboratory work by students (Gage, 1881 & 1888; Trowbridge, 1884; Chute, 1889). These textbooks frequently bearing the newer title *Physics* emphasized two central tenets of the Scientific Revolution: thinking for oneself and investigation through experimentation. At the same time universities, led by Harvard and the John Hopkins model, began to change their entrance requirements to match the new expectations. This rising popularity of the laboratory method can be understood as a consequence of the rapid scientific and technological advances of the period which saw the expansion of the railroads, telegraph lines followed by the telephone and then electric lighting. In a world in which technological advances came to be part of everyday life, the investigative spirit of the *Scientific Revolution* pushed into the American classroom.

The History of Science Education

Given the prestige our contemporary society has conferred upon science, one might imagine the story of science, how it grew and changed, resembles an exhausted mine. And yet the educational side of the story, of how students learned science and what they were taught, largely remains to be written. Far from the epicenter of science, education, or historical studies, the history of science teaching lingers on the periphery (Heering and Wittje, 2011). While Olesko (2006) has argued a substantial literature already exists on the history of science pedagogy most studies cited it that study focused on collegiate experiences in Europe. What about the experience of high school students in America? What do we already know there? DeBoer (1991) published twenty-five years ago published a book-length history of ideas in American science education which has served as a standard introduction since. A more recent summary is provided by Rudolph & Meshoulam (2014). However, much work remains to be done as both studies provide a narrative framework, rather than a detailed account of any period. A body of scholarly articles is emerging, focusing on particular aspects of the larger narrative, which taken together provides a clearer picture of past practices in science education.

Rarer still are studies focused on the evolution of instruction in particular branches of science. Physics is one of the better studied branches. Meltzer and Otero (2015) published a quick summary of key figures and movements in the history of American physics education.

Otero and Meltzer (2016) have also started to examine the lessons today's physics teachers can learn from the discipline's past. Prior to their work, isolated studies were produced periodically, with a strong tradition of emphasizing the laboratory. Rosen (1954) for example sketched out a history of the American physics laboratory up to 1910. A year later, Kelly (1955) blamed the "critical" condition of high school physics in the US on the decline of laboratory instruction, taking a historical approach to building the argument. Nearly twenty years later, Moyer (1976) returned to the topic, examining the role of Edwin Hall in the emergence of laboratory-based physics instruction. Donahue (1993) sought to understand who was best served by the curriculum, studying the shift in physics pedagogy from 1930 to 1965, from "progressive" to "discipline- based" instruction. These studies have provided stepping stones across the decades, serving as a springboard for a deeper dive. It is the aim of the following study to trace the development of science pedagogy as found in the textbooks of the early progressive period.

Current Ideals of Science Learning

The view of science as more than a body of knowledge, that it is also a way of knowing resting upon direct and personal investigation is now well accepted in science education (AAAS, 1989; NSTA, 2000; NGSS, 2013b). As currently conceived, science is as much a matter of doing as of knowing. As the American Association for Advancement of Science described, "Science tends to differ from other modes of knowing" through its "particular ways of observing, thinking, experimenting, and validating" ideas (AAAS, 1989, Chapter 1). The National Science Teachers Association (NSTA, 2000) stated its view of science as a process of information gathering resting on the testing of information. "Science is characterized by the systematic gathering of information through various forms of direct and indirect observations and the testing of this information by methods including, but not limited to, experimentation" (Ibid., p. 1). It is an integral part of our current vision of science that it is an active process of testing ideas. Key elements of this process are: observations, testing and experimentation.

The National Science Teacher Association (2000) gave a lengthier distillation of the nature of science in its position statement,

> Although no single universal step-by-step scientific method captures the complexity of doing science, a number of shared values and perspectives characterize a scientific approach to understanding nature. Among these are a demand for naturalistic explanations supported by empirical evidence that are, at least in principle, testable against the natural world. Other shared elements include observations, rational argument, inference, skepticism, peer review and replicability of work (Ibid., p. 1).

The NGSS in describing the nature of science states, "In common parlance, science is both a set of practices and the historical accumulation of knowledge" (NGSS, 2013b, p. 96). The NGSS continues, "Students should develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting, and analyzing" (Ibid., p. 96). Both the NSTA and the NGSS make clear the current view of science as a multidimensional process which involves several acts of investigation beyond rote learning of the content knowledge. Students are expected to do far more than just learn the content, the facts of science. They are expected to explore, to think, to investigate in much the same was as practicing scientists.

The Scientific Revolution

While the notion of the Scientific Revolution is surrounded by disagreement, there is general agreement that rational doubt and investigation through experimentation were two major ideals which emerged from it (Boas, 1962; Cohen, 1994; Shapin, 1996; Henry, 2008). It was these ideals of observing nature directly, of finding out the truth for one's self and doing so through experimentation which embodied the spirit of the movement. As will be documented in the next chapter, these ideals began to enter the American classroom late in the 19th century, but long before that they were at the heart of the emergence of what we now know as modern science. This chapter examines how science is commonly conceived; its epistemology, ontology and axiology and how its values can be traced back centuries before they entered the American classroom.

A major feature of the scientific revolution involved looking past what had been known, no longer accepting the knowledge of antiquity as adequate. As Marie Boas wrote, "One of the most noticeable changes in the period between 1450 and 1630 is the change in attitude towards the ancients. In 1450 men attempted no more than comprehension of what the ancients had discovered, certain that this was the most that could be known (Boas, 1962, p. 345). By the end of the period, scholars questioned the veracity of ancient learning and sought instead new and better solutions. Boas saw these leaders of the scientific renaissance as seeking new answers, their own answers on how nature was structured and functioned.

> Sixteenth-century scientists were filled with the twin spirits of novelty and rebellion. Consciously turning away from established views, eagerly making discoveries and discussing new ideas, they came to feel more and more surely that

> totally new methods were required for the effective investigation of nature (Ibid., p. 238).

There was during this period a strong sense that the spirit of science was connected with something new, things as yet undiscovered. Fast forward several hundred years to America in the 1860s, and in classrooms around the country textbooks still encouraged students to accept the knowledge of wiser men and trust that what they learned from books were the best answers available. Just as scholars of the early 15th century sought nothing more than to understand what others had discovered, so too did students of the early 19th century.

H. Floris Cohen (1994) offers a more refined and balanced assessment of the "Quarrel of the Ancients and Moderns" and its implications. Indeed, thinkers of the 17th century did attack the authority of classical scholars, but it went far beyond merely Galileo and Aristotle. Summing up the views of proponents of the new sciences Cohen writes, "In other words, we should not feel a blind reverence for past thinkers: We ought to weigh carefully the pros and cons of their arguments, but it will not do, in matters scientific, to forgo forming an independent judgment of our own" (Ibid., p. 159). Cohen continues to refine his perspective, pointing out that even Galileo still held many ontological notions stemming from the ancient Greeks; the quarrel was really more about the Aristotelians preference for logic rather than the Modern preference for arguments based on actual experience. Just such a spirit of investigation and reasoning by induction as the scholars of the scientific renaissance was what advocates of the laboratory method sought to bring to American students in the late 1800s.

Let us now look at three figures famous often associated with the scientific revolution for exemplifying its values: Francis Bacon (1561-1626), Galileo Galilee (1564-1642), and Rene

Descartes (1597-1650). In the writings of these three figures one finds expression of distain for knowledge authenticated by authority alone and the need for first hand investigation of natural phenomena. Bacon (1620) in his *The Great Instauration* attacked classical knowledge as leading down a blind alley. "That wisdom which we have derived principally from the Greeks is but like the boyhood of knowledge and has the characteristic property of boys: it can talk, but it cannot generate; for it is fruitful of controversies but barren of works" (Bacon, 1989, p. 8). The very fact that classical debates were long standing and unending revealed their error. Bacon held that more progress was made in "the mechanical arts" which were bringing "to further perfection the things invented," than by the long succession of "masters and scholars" who represented the various schools of philosophy (Ibid., p. 8). Bacon vehemently opposed a tradition of knowledge based on book learning and disputation, rather than on new investigation, experimentation and culmination.

Galileo Galilei was likewise ready to challenge inherited wisdom. Galileo famously built his own telescope and turned it towards the night sky. The observations from this investigation led him to challenge notions of the cosmos which had stood for long centuries in his *A Sidereal Message* (1610). One such notion was that of stars and planets being perfect, heavenly bodies. When the results of his telescopic investigations yielded results opposed to this notion Galileo wrote,

> The surface of the moon is not even, smooth, and perfectly spherical, as the majority of philosophers have conjectured that it and the other celestial bodies are, but on the contrary, rough and uneven, and covered with cavities and

> protuberances just like the face of the Earth, which is rendered diverse by lofty mountains and deep valleys (Galileo, 2012, p. 10).

Galileo thereby set an example of the scientific spirit emerging during the seventeenth century: the task was to make one's own inquiry, and if the new observations and data disagreed with what was taught in books, one was to challenge the accepted notions.

Perhaps the most famous rejection of all accepted knowledge was that of Descartes. In his *First Meditation* (1641), he acknowledges that up to that since childhood he had too ready to accept the views of others only realizing later how far he had been misled.

> I realized how many false opinions I had accepted as true from childhood onwards, and that, whatever I had since built on such shaky foundations, could only be highly doubtful. Hence, I saw that at some stage in my life the whole structure would have to be utterly demolished, and that I should have to begin again from the bottom up if I wished to construct something lasting and unshakeable in the sciences (Descartes, 2008, p. 13).

In order, "to construct something lasting and unshakeable in the sciences" Descartes felt, "the whole structure would have to be utterly demolished" having been, "built on such shaky foundations"; for that reason, he withdrew "into seclusion" where he might be able to devote himself "seriously and without encumbrance to the task of destroying all my former opinions" (Ibid, p. 13). It has been noted that Descartes place in the Scientific Revolution is "hard to define" because "the overall frame in which his thought was cast was fundamentally at odds with the conception of the task of the scientists formed by his innovative contemporaries" (Cohen, p. 160). While Descartes did attack the uncritical acceptance of knowledge, he sought to "set himself up as the new authority" able to "pull off what previous thinkers had failed to achieve" (Ibid., p. 160). Descartes most famously found truth through critical thought, rather than experimentation and direct observation of phenomena, bringing us to the other important consequence of the scientific revolution: investigation through experimentation.

Section Summary

In the preceding section I have sought to provide the reader with a lay of the land and provide an orientation to what lies ahead. I began by discussing what I initially thought I would research, and why it changed. This was followed by a describe my central phenomenon *the laboratory method*, followed in turn by a short review of leading scholarship in the history of science education to provide context. As this dissertation focuses on the ideals behind teaching traditions, I next reviewed what our current expectations are and then showed that the core of these ideals date back to the *scientific revolution* in sixteenth and seventeenth century Europe. In the next section, I give a synopsis of the state of science education at the end of the 19th Century. I do this to set up the events which preceded it, to help the reader understand their importance.

Secondary Science Education in America at the End of the 19th Century

In this section I will briefly examine some of the thinking around secondary education generally and science teaching specifically at the end of the 19th century in America. This will set the stage for the deeper dive into earlier documents. American education in the late 19th and early 20th centuries has been well studied both in terms of general educational transformations (Cremin, 1964; Kliebard, 1995; Krug, 1969; Tyack, 1974) and those in science (DeBoer, 1991; Sizer, 1964). The discussion here comes from work done early in my research journey, but I have retained them here to set the stage for what lies at the heart of this dissertation, namely the emergence of *Physics* from the discipline of *Natural Philosophy* in the 1880s. This portion of my dissertation around four topics: the structure and logistics of schools, the perceived purpose of education, notions of pedagogy, and thoughts about laboratory work. While neither definitive nor exhaustive, the discussion here serves to present some of the voices which became dominant.

General Discussion

The narrative at the heart of this dissertation examines the process by which the laboratory method gained popularity in the 1880s and became a distinguishing feature of the emerging tradition of *Physics* as a high school course. Because the period which followed has been more thoroughly studied, it will be beneficial to look at what followed, before returning to see how *physics* emerged as a curricular tradition. In the classic narrative description of *A History of Ideas in Science Education* DeBoer (1991) focuses on developments following the *Report* of the Committee of Ten (1893), with only limited coverage of what came before. In DeBoer's narrative, a significant transformation in American secondary science education occurred between the 1893 publication of the *Report of the Committee of Ten* and the 1918 publication of the *Cardinal Principles of Education*. People contemporary with the period of study saw a need for educational change, both in science and more generally, due to both social factors (such as increased enrollments and diversified student bodies) and changing ideas in pedagogical theory. The notion that the mind was a muscle and so skills learned in one domain could easily be transferred to another, a theory known as *mental discipline*, lost ground after playing a prominent role in the *Report of the Committee of Ten*. Educational aims, as expressed in the *Cardinal Principles*, shifted towards the social development of the student as mastery of content knowledge receded as an educational focus. With this shift from intellectual to social development, laboratories gave up their central position for a while as project-based lessons became the new fashion.

Structure and Logistics

One of the enduring challenges facing the American school system at the end of the 19th century and well into the twentieth was the retention of students. This will be discussed further later, but for the purpose of this section it suffices to say the brevity of most students schooling created considerable discussion about what best to fill those precious years with. As Commissioner Harris complained,

> Even at the elementary level, students averaged less than five years of schooling in the cities and three years in the country. But with our short school period, lasting on the average for five years with us in the city, and about three years, more or less, in the country, there is the utmost need of the most careful selection of what is essential (Harris, 1895, p. 9).

This short window of opportunity to teach and reach students created a great pressure on the organization of schools to meet students' instructional needs as quickly and as effectively as possible. Even in 1918, the Commission on the Reorganization of Secondary Education recommended cutting elementary education from eight years down to six and focus on the needs of 6- to 12-year-olds because so few students obtained a secondary education (NEA, 1918). Doing so would cause students to progress more quickly into secondary schools which were being designed to meet the needs of students between the ages of 12 and 18. Not only did they recommend shortening the elementary period in general, but furthermore any student who would be better served in the secondary school ought to be promoted, regardless of whether or not they had progressed through a prescribed curriculum.

Part of the solution in 1918 was the "Comprehensive High School," where as many subjects as possible were taught. The idea behind the comprehensive high school was partly to bring a wide diversity of students together, for the future benefit of society and themselves.

> When effectively organized and administered (see pp. 27 to 29) the comprehensive high school can make differentiated education of greater value to the individual and to society, for such value depends largely upon the extent to which the individual pursues the curriculum best suited to his needs (NEA, 1918, p. 25).

Such a school would foster their development as citizens by becoming familiar with the many disciplines. The comprehensive high school was also able to offer more practical or specialized courses in various vocations to generate student interest. Lastly, by offering all things under one roof, if a student changed their course of interest, they did not need to change schools. The comprehensive high school was in 1918 seen by the Commission as clearly preferable to the specialized school which focused exclusively on a few subjects.

While many more students were attending secondary schools in 1918 compared with 1893, the Commission fought to further increase retention rates. Secondary education had come to be seen as a public good not only for the few, but also for the many. (Citation?) To this end, the Commission held that schools should be reorganized so as to encourage "every normal boy and girl" to remain in school until 18 years of age, either on a full or part-time basis. This was seen as such an important point that the Commission sought legislation to require a minimum of eight hours of schooling for all youth up to the age of 18.

The pressure to retain students increasingly shaped the curriculum offered by schools. The Committee of Ten, which began the attempt to create national recommendations regarding American schools and schooling struggled with the questions of what subjects ought to be taught at a given grade level and for how many hours a week. Their purpose was “to consider the proper limits of its subject, the best methods of instruction, the most desirable allotment of time for the subject, and the best methods of testing the pupil's attainments therein" (NEA, 1893 p. 3). To do this, the Committee formed nine conferences, based on the major branches of learning, to form recommendations in each specific area. These conferences included: Latin; Greek; Mathematics; Modern Languages; English; Physics, Astronomy, and Chemistry; Natural History; History, Civil Government, and Political Economy; and Geography.

One can read the *Report* of the Committee of Ten as a fight among the disciplines for hours of instruction. The conference of Physics, Astronomy, and Chemistry for example insisted on “at least 200 hours...devoted to the study of physics” and another 200 hours “given to the study of Chemistry,” with both being “required for admission to college.” So specific were the recommendations of the committee, they included making a list of “50 experiments in Physics, and 100 experiments in Chemistry” to be approved as standards for college admission (NEA, 1893, p. 118). Clearly, the conference considered college preparation as a main goal of secondary education.

Commissioner Harris, a strong advocate of the humanities, felt education at the elementary levels ought to focus on the basic skills of reading, writing and arithmetic. Even so, he made a special plea whether some experience with natural science could not be offered even the younger students. "Can we not give those children who study five years or a less time in our schools, some outlines of Physics and Natural History, which will be of great service to them in after life, and for the time being not interfere seriously with the prosecution of elementary studies?" (Harris, 1895, p. 13). One hour a week of science Harris felt would not interrupt the focus on fundamental skills such as reading, writing and arithmetic too much, and yet serve the students well if they left school with only five years of education as so many did. If their schooling was so brief, one could not wait to teach them the more advanced subjects.

Given the very limited amount of education students would obtain prior to the 20th century, Commissioner Harris would have the curriculum severely focused on the academic and the theoretical. It ought to include only such material as the student could not learn from others outside of the school. In other words, nothing which his parents, friends, or work could teach. The curriculum ought to have "a general theoretic bearing on the world" such that the student would understand "the institutions and character of the human species" (Ibid., p. 9). In science this meant that before a student left the eighth grade, they ought to learn in physics about such subjects as: gravitation and pressure, cohesion, capillary attraction, mechanical powers, heat, light, electricity and magnetism (Ibid., p. 25). For Harris the best way to ensure students received the vital knowledge they needed for their future lives was to cut quickly to the abstract notions which could later be applied. There was no time to waste on vocational or practical learning that could be learned after a student left school.

Although they sought to enforce school attendance with legislation, the Commission in 1918 felt the need to shape secondary curriculum around the very real loss of students through the grade progression. In their own words, "Since a large portion of pupils leave school in each of the successive years, each subject should be so organized that the first year of work will be of definite value to those who go no further; and this principle should be applied to the work of each year" (NEA, 1918, p. 17). Curriculum in 1918 ought to be so structured that each year of a subject needed to justify what it contributed to a student's' education without reference to further education. Subjects could not be justified in terms of preparation for further study but rather must satisfy the needs of students whose education might end with that course.

Purpose of Education

Much of the struggle over the American curriculum centered on the purpose of secondary education. Was the point to provide students with some general practical knowledge, to shape their character, to prepare them for college and careers, or to solve the problems of society in the next generation? This is a theme which continues to be debated, although there have been repeated shifts in which argument appears to have the upper hand.

In 1893, the emphasis was on preparing students for life after school, whether this was in a career or in college. The *Report* of the Committee of Ten explicitly stated that the "main function" of the American high school was "to prepare for the duties of life" those students "who show themselves able to profit" by such an extended education (NEA, 1893, p. 51). The committee made clear that any secondary school system designed to be used nationwide ought to focus on those students who would *not* go to college and yet still to prepare every student so as to be *able* to attend college (Ibid., p. 52). This led to the recommendation, quite at odds with the later ideas of the Commission that all students ought to be taught the same while they attended school. For members of the Committee of Ten, this idea of equal education for all was a key point.

> Ninety-eight teachers, intimately concerned either with the actual work of American secondary schools, or with the results of that work as they appear in students who come to college, unanimously declare that every subject which is taught at all in a secondary school should be taught in the same way and to the same extent to every pupil so long as he pursues it, no matter what the probable destination of the pupil may be, or at what point his education is to cease (Ibid., p. 17).

While the Committee of Ten had placed great emphasis on teaching all students the same content using the same means, regardless of "probable destination" this ideal could not be maintained in the face of the increasing diversity and number of students attending American secondary schools in following years.

Commissioner Harris was a champion of both utility and character. He felt that since the natural sciences were creating the basis for most of the economy and were thus driving the "elevation of the masses" they were so important as to be taught even at the elementary level (Harris, 1895, p. 2). Harris felt that a "school must furnish the pupil theoretical insight" for such knowledge could be applied later "to any one of the many trades or professions" (Ibid., p. 9). Education needed to be useful later in life, and the key to that was to teach theory, to instruct students in abstract concepts which could be applied anywhere, regardless of later occupation or station. Such an idea as theory being ultimately more useful than every day, practical experiences was also to diminish as the years progressed and classrooms became too crowded and heterogeneous to teach topics removed from pedestrian life.

Schools needed to do more, however, than provide theoretical knowledge. They also needed to develop good character. Habits such as: "order, neatness, cleanliness, earnest ness, industry, punctuality, self-respect, self-control, obedience to rule, kindness, forbearance, courtesy, considerateness, affability and politeness, sympathy and love" ought to be the end result of any "well-disciplined school" (Ibid., p. 10). Ultimately, Harris found,

> Knowledge of men is more important than knowledge of things, as we all find when we grow up and try to succeed in life. We learn that we can do nothing nor achieve anything without the aid and consent of our fellow men. We must, therefore, understand the springs and motives of human action, both the permanent ones and the ones that control temporarily (Ibid., p. 10).

A champion of the Humanities, this notion of education serving a socializing function was one he shared with the Commission whose report was published twenty years later.

The theme of developing character continued to play large, even as notions over the means of doing so shifted. In their *Principles of Secondary Education*, the Commission on the Reorganization of Secondary Education claimed that, "Education in a democracy, both within and without the school, should develop in each individual the knowledge, interests, ideals, habits, and powers whereby he will find his place and use that place to shape both himself and society toward ever nobler ends" (NEA, 1918, p. 9). This would be done by focusing on: health, fundamental processes, home-membership, vocation, citizenship, use of leisure, and ethics. In this sense, theoretical content played a limited role in education. Secondary schools were to be less about mastering chemistry, history or literature, and rather more about contemporary life.

Schools ought not to be little academies or universities for teenagers, but rather miniature versions of the wider community. Their primary function was socialization of the youth. This is why the Commission held up the comprehensive school as the ideal type. Only it could serve as "the prototype of a democracy," causing students to be divided into various groups and yet come to recognize their "common interests and ideals." Such schools would prepare students for life and benefit society in "a natural and valuable" way (Ibid., p. 26). Throughout the period from 1893 to 1918, educators sought to create a school experience which would improve the lives of students. It was never far from the minds of the reformers that schools ought to benefit both students and society by preparing America's youth for what life expected of them. The changes which occurred during that twenty-five-year time span centered around how best to prepare students. Over the decades between the *Report of the Committee of Ten* and the *Cardinal Principles of Secondary Education*, school became less and less about content master, and more and more about fitting individuals to the mold of society.

Pedagogy

As seen in the general views on the purpose of education, shifts occurred in the pedagogies recommended by the reformers. At the time of the Committee of Ten, Greek and Latin, together with Mathematics held dominance as the most important subjects. This importance was due to the long-standing tradition of education serving to distinguish the common man from the gentleman. It was defended with the argument that Greek and Latin, due to their difficulty, provided mental discipline. This strength of mind would carry over into any other intellectual endeavor and justified the pains taken to master dead languages. Members of the "modern" subjects, including the sciences, found this an early barrier they needed to overcome.

The science conferences, as the other conferences in modern subjects did, needed to convince the Committee at large that they too required and demanded intellectual rigor (NEA, 1893, p. 13). For this reason, much of the talk regarding pedagogy at the end of the century was centered around the demands of the subject. Harris reveals this in describing the need to begin with observations in science before moving towards understanding. “It is, at first thought, strange — although it is true — that powers of observation are to be strengthened only by teaching the pupil to think upon what he sees. The process is one of division (analysis) and classification, and, secondly, of tracing causal relations” (Harris, 1895, p. 32). From such expectations of rigorous inductive and deductive thought sprung practices equally demanding of teacher and student.

As Commissioner of Education, Harris had much to say regarding best practices. It was not that he espoused any one method. Indeed, he debated what the difference was, “between the oral and the so-called text-book method, and what are the merits and defects of each?” (Ibid., p. 15) For Harris, the key was knowing the strength of each, and then using them correctly. “The excellence of the oral method should be its freedom from stiffness and pedantry, and its drawing out of the pupil to self-activity in a natural manner” where as “The excellence of the text-book method consists in getting the pupil to work...and to overcome difficulties by himself, instead of solving them for him.” Correctly used, either method could instill mental discipline in a child.

Even good methods, if used incorrectly or “abused” could lead to bad results. The danger was a lazy teacher, for such a teacher would in turn create lazy students. Finding competent, hardworking teachers appears to have been as difficult then as now. The trouble was teachers who failed to prepare adequately ahead of time and got around this by using the textbook during recitations to ask students’ questions. Harris clarified, “Indolent teachers lean upon the text-book and neglect to perform their own part of the recitation” (Ibid., p. 16). By using the textbook to find information themselves but asking students to have memorized such information and to answer questions derived therefrom, teachers created a situation in which children simply crammed information without comprehension.

Harris laid out five keys to using the oral method (or recitation) correctly. These keys included: focusing on the main points of the lesson, using students' own language rather than that of the book, of connecting the lesson to the students' prior knowledge (both lived and learned), and the assessment of the students' strengths and weaknesses. He suggested that a regulation be put in place "prohibiting" the teacher from using the textbook whenever students were expected to do without it. Instead, it was recommended that teachers use "a syllabus of topics or questions" prepared ahead of time (Ibid., p. 17). The emphasis of Harris's advice was repeatedly on the accuracy, individual effort, and consistency of the lesson, and not on social development or motivation of the student.

Laboratories

The emphasis on accuracy and effort seen above in Harris's recommendation to teachers is repeated in the prescriptions of the Conference on Chemistry, Physics and Astronomy in their part of the Committee's report. According to resolution 13 of that conference, good scientific preparation required three things: careful laboratory work, diligent use of a textbook, and an intelligent teacher.

> It requires no argument to show that the study of a textbook of Chemistry or of Physics without laboratory work cannot give a satisfactory knowledge of these subjects and cannot furnish scientific training. Such study is of little, if any, value. On the other hand, the mere performing of experiments in a laboratory, however

> well-equipped the laboratory may be, cannot accomplish what is desired. Further, a pupil may work conscientiously in the laboratory, and study his textbook thoroughly, and yet receive a very inadequate training. He needs an intelligent teacher to aid him in interpreting the statements of the book and the phenomena observed, as well as to show him how to work (NEA, 1893, p. 119).

Without laboratory work, what the student learned was not science. Without reference to textbooks, students would be limited in their knowledge, without a diligent teacher, much of the work would become “loose,” “harmful” and “bad.” Rigor here was key.

Another evil the conference on Chemistry, Physics and Astronomy sought to correct was the notion of students “rediscovering” scientific laws. The purpose of resolution 21 was to put an end to this erroneous idea:

> The pupils may, to be sure, become imperfectly acquainted with the methods of work that have led to the discovery of the laws, and they will, no doubt, come to see more and more clearly the relations between the facts and the laws, but...it is wrong to speak of the work of the pupils as leading to the discovery of laws (NEA, 1893, p. 121).

Rather than emphasizing creativity and imagination on the part of students, the expectation in 1893 was that students focus on quantitative work which led them to better understand the work of those who had gone before and done the actual discovering. There was to be no role-playing here on the part of the students.

The discussions among members of the conference led to two recommendations showing the importance of laboratory work. The first was that science, “the study of simple natural phenomena” be introduced at the elementary level and taught “so far as practicable” by means of “experiments” and the “use of simple instruments” of measurement (Ibid., p. 117). At the secondary level, Chemistry and Physics ought to be studied through a balance of “laboratory work, text-book, and thorough didactic instruction carried on conjointly,” with half the time spent on laboratory work. It was not only the physical scientists who placed a heavy emphasis on exact observations and accurate records.

> Like the report on Physics, Chemistry, and Astronomy, the report on Natural History emphasizes the absolute necessity of laboratory work by the pupils on plants and animals; and would have careful drawing insisted upon from the beginning of instruction. As the laboratory note-book is recommended by the Conference on Physics, so the Conference on Natural History recommends that the pupils should be made to express themselves clearly and exactly in words, or by drawings, in describing the objects which they observe" (Ibid., 1893, p. 27).

This focus on strict observations of details leading by a slow, reasoned progress of thought towards and inductive understanding of the material being taught did not last long. As the new century dawned, Latin and especially Greek lost their hold as the pre-eminent subjects together with the decline of mental discipline as a basic principle of pedagogy. Increasingly, pedagogies emphasized the child and the curriculum centered on social concerns. For this reason, the Cardinal Principles of Education had much less to say regarding methods than regarding the aims of instruction.

Section Summary

In this section I have sought to provide a sense of the challenges and changes occurring in American secondary science education at the end of the 19th and into the early 20th centuries. This summary looked at four main areas of schools and schooling: the structure and logistics of schools, notions regarding the aims or end goals of schooling, how such lessons ought to be taught, and finally what the role of the laboratory was to be in secondary science education. My purpose in doing so was to ground the reader in the period to help them understand what followed the emergence of physics, what issues remained and what had changed. In the next chapter I take the reader further into the literature, both secondary and primary.

Chapter Summary

This opening chapter sought to familiarize the reader with the topic of study, namely the laboratory method, and some of the conceptual framework which will be used to understand the findings discussed later on. The first section of the chapter introduced some of the key thinking underlying this dissertation. High school *physics* as an instructional tradition emerged in the US during last several decades of the 19th century. The adoption of the laboratory method, which began in the 1880s, was a central feature of this new tradition. The second section set up the significance of what is discussed later through a short overview of what followed this emergence and displacement. While the narrative of how *Physics* displaced the tradition of *Natural Philosophy* is the heart of this dissertation, understanding it significance is gained by looking at the broader context of the social changes America was undergoing before during and after the 1880s.

CHAPTER 2. LITERATURE REVIEW -- PERSPECTIVES

Histories of science education have frequently been justified, as have histories generally, on the basis of bringing clarity to present circumstances (DeBoer, 1991; Rury, 2002; Lagemann, 2005; Gaddis, 2006; Reese, 2007). Studying history allows us to assess the position of our own times more accurately through a comparison with the struggles and successes of past times. It also helps us understand how and perhaps why things have changed. As William J. Reese eloquently wrote, "History remains the central way to understand how individuals and society change over time, providing a kind of perspective unavailable in any other discipline of body of knowledge" (2007, p. 8). In *The Teacher Wars,* Diana Goldstein (2014), argues the same failed attempts at reforming American schools continue to resurface due to the lack of public knowledge regarding past efforts at reforming the profession.

History is the most useful, the most insightful when we are able to overcome "the lure of presentism" which is the "tendency to believe that society today is somehow different--even better--that the social order of the past" (Rury, 2002, p. 3). When we mistakenly believe that people in former times were "old-fashioned" or that "the public knows so much more today" we become insensitive to the lessons of history. To get the most out of a historical study, we must not be too quick to tear lessons from the fabric of the past but seek to understand the lessons we may find within the context of the period. History also serves as a literary art, appealing to our innate desire to journey into the past, and relive distant eras. In writing this dissertation, it is hoped to appeal both those desiring to understand the current calls for re-energizing and reforming science teaching in America and those to who are intrigued about a time not our own.

History, Science and the History of Science Education

This section first reviews some of the more recent historiographic scholarship regarding the history of education, examining in other words how and why histories of education have been written. The discussion focuses on why the history of education matters and what other scholars see as the hopes for its future. It then takes a look takes a look at why science education matters, putting the past in the context of the future. It argues that scholarship around the history of science education is important not only in its own terms as a fascinating branch of history, but also because of the importance of science and technology to the future. This section ends by reviewing some exciting scholarship looking at the history of science education and what other scholars are currently working on.

The Relevance of the History of Education

A number of scholars (Gaither, 2012; Lagemann, 2005; Ramsey, 2007; Rury, 2006) perceive that the history of education faces a significant challenge in remaining relevant. The discussion turns on the relationship of the field with its parent disciplines: that of history and of education. Lagemann (2005) argues the importance of history as an interpretive tool in educational research but stresses the literary function over the scientific. While she recognizes that history is Janus-faced, both something of a science and an art, Lagemann finds history gains its relevance and meaning when its “artistic or imaginative aspect is featured” (Ibid., p. 22). This despite being a strong advocate of more science in educational research. It is in the study “enduring dilemmas or current puzzles” (Ibid., p. 17) that the humanities make their great contribution to the field of education. As such, she directs historians of education to study the current rise of science within education using the traditional tools of history, rather than seeking to practice a more scientific form of art.

Rury (2006) seeks future directions for the history of education based on lessons from the history of science, the history of economics, and the history of law. These other disciplinary histories, like the history of education, are situated between one parent discipline (i.e. science, economics, and law) and another (History). This leads to confusion over whose methods and research priorities to adopt. Rury argues the practice of historians of education ought to, "be informed by a coherent agenda taken from the field itself or its allied non-historical scholarship" (Ibid., p. 595). He perceives a "parallel model" in which the History of Education proves "useful" and survives by becoming "broadly conversant with research questions and related methodological consideration in education" (Ibid., p. 595).

In the case of this dissertation, the essential tensions discussed between the research agendas of parent disciplines is particularly acute as this dissertation lies at the intersection of three such parents: science, history and education. My methodology, discussed further below, will align most closely with that of history, and yet seeks to be of service to science and education. As a writer, this entails sailing between Scylla and Charybdis, in order to avoid the sin of presentism. The lessons learned from the past will be compared with the concerns of today in the conclusion of this dissertation to see what insights may be gained. America is currently exploring the ability of the Next Generation Science Standards to improve instructional practices. Perhaps there will be useful parallels with past reform efforts, but these are best traced after the historical work is completed. The following section discusses the value of science education and why it is important enough to warrant so much debate.

Why Science Education Matters

Although about the past, this dissertation is even more so about the future. Our global society is becoming ever more techno-centric and we need debate over how best to integrate the coming technology into our way of life. There is growing concern that the coming combination of automation and artificial intelligence, of robots who can learn, will lead to large scale technological unemployment (Frey and Osborne, 2013). When futurists describe what may lie ahead, they describe a world in which the human-digital interface has become seamlessly smooth; humans and machines work as a harmonious one and technology serves to deepen, enrich and improve the human experience. Augmented reality, holographic projections, and voice control will have made computer keyboards and screens obsolete (Gribetz, 2016; Kipman, 2016). We will be surrounded and immersed in a world in which artificially intelligent personal assistants guide us in making daily decisions, in which we are transported by self-driving cars, trains, and drone taxis, and the bulk of the economy revolves around managing resources through digital data streams (Chase, 2015). This future is not as far away as it may seem.

My concern is with developing schools which allow students' dreams to flourish, guiding their learning by engaging them in projects reflecting the complexity of the real world, and allowing them to enter a world which has not yet come to be. To predict what lies ahead, however, one must enter the past in order to see the relevant vectors moving through space and time. How schools teach and incorporate STEM content will play a major role in determining how future generations come to terms with these breakthroughs. In order for students to discuss how technology influences society, they must first experience science itself and then learn how science influences technological advances.

The Future Is A Consequence of The Past

Given that many states in the U.S. are currently in the process of implementing new standards in K-12 science education, it seems a timely endeavor to trace how practices in science education responded to social changes in the past. The goal is not only to explore the past and better understand how we got to here, but also to clarify the nature of change in science education and examine how present reforms relate to those of the past. If our children, and ourselves, are to master the rising tide of digital infiltration into our lives we must engage with opportunities to understand these advances, follow their developments and discuss their implications for ourselves, our children and our increasingly global society. If the current rate of technological advance continues, our lives will become ever more deeply entwined with the rapidly expanding array of products designed by those working in the STEM fields: physicists, chemists, data scientists and engineers.

Understanding the emergence of *Physics* as a high school subject is important to understand the challenges we face today in developing first rate science instruction. All of our students need and deserve access to both the knowledge and the process of science, given the significant role of science and technology in our world today, (NSTA, 2003; NSTA, 2011). The new science standards known as the Next Generations Science Standards, or NGSS, seek to take students deeper into exploring how science actually functions by focusing on the multiple dimensions of activity in which STEM workers simultaneously operate (NGSS, 2013). The thinking is that schools must play a significant role in helping young people to better understand how science and technological advances are interdependent. The Next Generation Science

Standards are, and can be fruitfully understood, as part of a history of past efforts at reforming science education.

Current Directions in the History of Science Education:

The work of George E. DeBoer (1991) serves as an excellent overview of the history of science education, but as is the case with general studies, it raised more questions than it answered. The work of more recent scholars (Heering & Wittje, 2011; Rudolph & Meshoulam, 2014; Meltzer & Otero, 2015) have brought my understanding of the period and the issues surrounding the topic into sharper focus. Of these other scholars in this field, the work of Meltzer & Otero has been particularly useful. Having developed a course on the *History of US Physics*, these two professors host a website for their course that includes a master bibliography complete with hyperlinks, providing useful access to many primary sources. Their research agenda is most nearly aligned with my own, making their work a valuable reference.

John Rudolph (2005) is another scholar who published regularly as so helps determine the current shape and direction of the field. Focused more on the history of science education generally, and less on physics specifically, Rudolph's work provides valuable context as to the wider changes occurring in science education during the late 19th and early twentieth centuries. An edited volume *Learning by Doing* (Heering & Wittje, 2011) has provided the perspectives of other recent scholars such as Michelle Hoffman, Richard L. Kremer, and Steven Turner. Hoffman examined the emergence of high school physics in America's northern neighbor, Canada, and reveals certain similarities but also major differences. Kremer looked at the introduction of laboratory exercises in physics classes at the University level, focusing on the events at Dartmouth College. Turner used the inclined plane as an entry point to provide a unique perspective on the changes in physics education during the same time period as this dissertation.

Meltzer & Otero (2015, p. 447) suggest that while "systematic physics education research (PER)" has helped to identify what instructional strategies are most effect, the history of reform efforts in physics education has been largely overlooked to the detriment to the field. The rationale is that by studying the history of the field and seeking to understand the fate of previous efforts at improving physics education, one could learn how to chart a better course for the future in the present.

> There has been little attention given to the history of physics education and to how the many reform efforts and often stormy debates of the past have played out. Few have asked, for example, how today's pedagogical initiatives differ—or don't differ—from those of the past, or what exactly has changed—or not changed—as a result of previous reform efforts. An obvious question to ask is "What must be done to avoid the shortcomings of previous efforts at reform?" (Ibid., p. 447)

In more recent work, Otero & Meltzer (2017) suggest that while general histories of science education, such as DeBoer's well regarded synthesis of 1991 are valuable for looking across the various sciences, more discipline-specific histories are needed. The reasons for this are that the history of each branch of science is unique, and deserve individual analysis, but also that important audiences are missed when the various sciences are lumped together. "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" (Otero & Meltzer, 2017, p. 39). The need to take a "discipline-specific" approach in my research has thus been clarified by this recent work of Meltzer and Otero. As I began my work from the *internalist* perspective of a former physics teacher, this approach fits my positionality well.

Several of the essays included in Heering & Wattle's (2011) edited volume *Learning by Doing,* such as that by Steven Turner, have also clarified my approach further. Turner championed the examination of, "textbooks, lab manuals, student notebooks, science teaching instruments and scientific instrument catalogues" in order to overcome the problematic over-reliance on the "speeches, writings and committee reports" of the period's professional elites (2011, p. 208). Turner cites Schiro's earlier use of term *scholar academics* to refer to these professional elites. In my proposal, I determined to use many of the same primary sources, with which to challenge both the work of contemporary scholars and the proclamations of the period's reformers. By drawing on the material culture from this period, especially the textbooks and instrument catalogues, Turner challenges the view that Edwin Hall, the Harvard *Descriptive List* and the NEA committee reports dominance in leading the "laboratory movement". Turner's claim that drawing on "a wider range of historical sources" such as work of "other textbook writers" has the power to alter even our basic understanding of the history of science education validates my proposal to examine a variety of the physics textbooks published for high school consumption during the period of transformation (Ibid., p. 239). Here is clear support for my approach.

Two other chapters in *Learning by Doing* need to be mentioned. Kremer (2011) underscores "the introduction of laboratory exercises" in the 1880s as "the most significant reform" in 19th century American physics instruction. Using the physics course at Dartmouth

University, Kremer asks whether America's student laboratory movement had a German origin as Olesko (1995) suggests. Like Turner's work, Kremer relies on examining the physics textbooks required for the course at Dartmouth, further validating my approach. Kremer concludes that the work of the American professor Edward C. Pickering was more influential than the German model in shaping the introduction of laboratory exercises at Dartmouth. Although his case focuses on the collegiate level, and a particular University, some of his findings may prove relevant to what occurred at the high school level. Hoffman (2011) conducted a parallel study to Turner's, examining the adoption of student laboratories in Canada during roughly the same period. Hoffman found that Canada's much greater bureaucratic centralization lead to much greater uniformity and celerity of adoption. Hoffman's study makes an interesting comparison piece to the American narrative.

In a recent work Rudolph & Meshoulam (2014) identify two major themes in the history of science education. These themes provide a useful heuristic for my own analysis. The first is that of the "practical-abstract continuum" along which the need for science education has been justified. Put another way, what better justified the inclusion of science as an important subject of study, "the immediate, utilitarian value inherent knowing how natural processes operate in the world", or "the idea that study of the organization and process of science promotes more abstract goals related to morality, virtue, analytical thinking, or aesthetics" (Ibid., p. 1). In their analysis, Rudolph & Meshoulam saw no clear historical trend along this continuum, only periodic vacillations. The second theme centered on a perceived shift in, "teaching science to make the everyday lives of students and citizens better to teaching science to ensure the success of the scientific enterprise" (Ibid., p. 1). Rudolph & Meshoulam claimed that prior to 1940, high school science was taught in a way that at least in theory, "provided tools (in either its content or methods) that could be used in other venues or for purposes outside of institutional science," however, following World War II and the vast federal investment into scientific research, science education was "aimed at sustaining the professional science community itself" (Ibid., p. 1).

Both of these themes are valuable as filters for my research, especially in addressing the question, "How does the past history of struggles over the physics curriculum between preparing scientists versus providing real life applications of physics get reflected in the new science standards for the teaching of physics?" While Rudolph & Meshoulam maintain that there has been a one-way shift towards science education which perpetuates and sustains the professional community, the *Framework* (NRC, 2012) make it clear that this goal is secondary to that of teaching, "What all students should know in preparation for their individual lives and for their roles as citizens in this technology-rich and scientifically complex world" (p. 10). Although it is true that, "current arguments cast the value of science education in terms of national security and global competitiveness" (Rudolph & Meshoulam, 2014, p. 22), it is not true that the new science standards no longer publicly justify science teaching "as something with a tangible benefit to students and citizens, be it moral, cultural, or practical" (Ibid., p. 22). This is an issue I wish to pursue further in the conclusion of my dissertation.

Regarding Turner's (2011) indictment of committee reports as being less important than previously thought, I still turn to Herbert Kliebard's remarks that such documents are best seen, "not as influencing the course of events, but as artifacts of a period from which one might be able to reconstruct what was actually happening in the teaching of school subjects" (1995, p. xiv). While I agree with Turner that a broader selection of sources needs to be taken into account, I also will not spurn the writings of the educational elite. In line with *synthetic history* as the currently dominant form of historiography, I seek to bring "the variegated historiographical arguments" together in order to "develop a comprehensive narrative" (Ramsey, 2007, p. 357). As Ramsey has put it, "The brilliant insights of creative historians have to resonate within the intellectual and popular communities of the society for them to have a profound effect" (Ibid., p 328). For this reason, I draw on the work of both Lagemann and Rury.

There is also the issue of "facts" in history. Whether or not they exist seems to miss the point; more important to my historiographic perspective is that good history serves a sense-making function. As Lagemann explains, "History is both a science and an art. It is a science because it is based on evidence — "the facts." It is an art because "the facts" do not speak for themselves. Their meaning must be imaginatively reconstructed, and they must be interpreted, and to do that, one must imagine how one fact relates to another" (2005, p. 22). Lagemann eloquently argues that to have an impact, "history must capture the imaginations of its readers to be of moment. It only becomes significant when it connects with enduring dilemmas or current puzzles and, in so doing, helps one see the present in more depth" (2005, p. 17). In this regard her conclusion is quite similar to that of John Rury, albeit derived from a different perspective.

While Lagemann pushed back against all things becoming *scientific*, Rury reaches his conclusion from a comparison with other disciplinary histories, such as the history of science. Rury argues the practice of historians of education ought to, "be informed by a coherent agenda taken from the field itself or its allied non-historical scholarship" (2006, p. 595). In other words, the history of education proves "useful" and survives by becoming "broadly conversant with research questions and related methodological consideration in education" (Ibid., p. 595). This reasoning supports my decision to compare the reforms in physics education from 1888 with those of 2018. Rather than becoming "broadly conversant" with the questions and methodologies of education as a whole (a very vast field), I seek to focus on those of science education. For such reasons as increasing the relevance of my findings, I chose to write a *discipline specific* history and to close my dissertation by examining the historical changes and continuities found in the Next Generation Science Standards.

Section Summary

This section has reviewed some of the key literature around the topic of this dissertation. It began by looking that the relevance of the history of education and then at why science education itself matters. It argues that the future is a consequence of the past and that current research in the history of science education is yielding some very interesting and important fruit. This section has been the more formal part of the literature review; the next section compares two education systems to show how varied conceptions of education can be. It is followed by a third section which continues to build the historical setting of the dissertation by looking at the broader historical context in which the emergence of physics took place.

A Comparison of Two Educational Systems

This section compares two educational systems, that of Plato's Republic and that of America from the perspective of Charles Eliot. This is done not only to show how different two educational systems can be but reveal some of the key features of American educational systems contemporary with the period of this study. Charles Eliot was not only President of Harvard and architect of its elective system, but also a well-known reformer of education and chairman of the Committee of Ten report which serves as the historical bookend of this study. The educational system described by Eliot is then that which arose as physics emerged from natural philosophy. This helps to further paint the historical backdrop to the narrative at the center of this dissertation. The use of the comparative method hopes to add color, clarity and depth to this backdrop.

How the conception of life and civilization impacts education

George S. Counts in 1962 claimed that education did not necessarily free the minds of individuals but could be put to any number of uses. Whether a system of education was a force for good or ill depended merely upon the "conception of life and civilization" which underlay it (Ibid., p. 62). As Counts argued, it is indeed true that education can, and has, served many ends; it can and has been put to both good and evil ends; and its purpose has been as varied as the cultures which have employed it. When taken as all that molds the minds of men and women, as John Dewey (1916/1960) did, education serves to perpetuate the norms and values of society, or influential individuals within it. For a society to survive, education must be a malleable combination of both conservative elements (the transmission of knowledge, customs, and values) and transformative aspects (by which the conservative elements are brought up to date). Without the transmission of cultural heritage, a society would find itself facing extinction; without transformation, a society becomes hidebound and out-of-touch, unable to meet the changing needs of external pressures. More interesting than the broad question of whether education serves as a tool for transformation or social conservation is the question of how, when and why it does so to different degrees. What causes educational systems to be more transformative (or less), and how does this correspond to the changes (desired or required) in a society?

Whether or not education was liberating can be traced back at least to ancient Athens and Plato. In his allegory of the cave Plato (380 BC/2008) expresses ideas similar to those of Counts. False education, known as sophistry, caused the enslavement of the mind. Most people suffered such a fate; they were like prisoners shackled in a cave mistaking the shadows upon the wall for reality. True education, stemming from dialectic, reoriented people towards the truth. Good education, "Should be...the simplest and most effective methods of turning minds around" (p. 245: 518d). This notion of liberation as the proper function of education is continued by later writers, such as Jean Jacques Rousseau (1762/2013). According to Rousseau, if the principle that, "The foremost good is not authority but freedom;" were applied to children, then "all the rules of education will follow." This worked because the truly free man, "wants only what he is capable of doing and does what he likes" (p. 234). Rousseau echoes a key tenet of Plato's philosophy: well educated people follow only those pursuits which they are good at and hence enjoy. It would be wrong to imply, as Counts did, that believing in education as liberating was necessarily "naive." Plato, Rousseau and other educational thinkers believed a good education was liberating, but not that all education qualified as good. Plato thought *true* education, a transformative and liberating education, was attainable only by those few with the best of souls.

In examining the philosophy and ideology which underlay the educational systems in different times and places, I will focus on the societies found in Plato's *Republic* and Charles Eliot's America. It is my hope that, given the marked differences between them, the comparison between an Ancient Greek ideal and a 19th century American reality will prove instructive. Plato's *Republic* is clearly an imaginary place, invented in the course of a dialogue on the topic of morality and government. Written in ancient Athens by a famous philosopher, the *Republic* does not describe a "real" civilization, but rather imagines an idealized society and the ideal education system need to create and support it. The other society and educational system I shall discuss, is that of America at the end of the 19th and start of the 20th century. During this period that Charles Eliot strove to help reform American education as rapid social changes caused concern about the disintegration of society. Charles Eliot, like Plato, looked to education to transform society, to create greater peace and stability.

Plato's Republic

There is a long tradition among scholars and intellectuals of returning to the *Republic* in an attempt to understand the roots of our own way of life. Benjamin Jowett (1972), wrote that throughout history even fragments of Plato have "ravished the hearts of men" who see in them "their own higher nature" (p. 4). Jowett found Plato to be the "father of idealism," and that numerous modern ideas, such as "the unity of knowledge, the reign of law, and the equality of the sexes" were "anticipated in a dream" by Plato. A more recent commentary (Taffel, 2004) claimed, "The dialogues of Plato stand alongside the Bible and Homer's *Iliad* and *Odyssey* as foundational texts of Western Civilization" (p. vii), with the "profound thoughts and arguments" found therein having affected, "Virtually all aspects of Western culture and belief throughout the centuries since" (p. xiii). This tradition of turning to Plato in order to understand the roots of today, is found in education as well as in history and literature. In seeking the foundations for the purpose of education, John Dewey returned to Plato and the *Republic*:

> No one could better express than did [Plato] the fact that a society is stably organized when each individual is doing that for which he has aptitude by nature in such a way as to be useful to others (or to contribute to the whole to which he belongs); and that it is the business of education to discover these aptitudes and progressively to train them for social use (Dewey, 1916, p. 102).

Dewey had a strong belief in the power of history to illuminate the present, holding that it gives "a more intelligent sympathetic understanding of the social situations of the present" (Ibid., p. 256). Given such precedence, Plato's *Republic* and ancient Greece seem a worthy place to begin my own examination regarding the purpose of education.

Greece at the time of Plato was no unified country, but rather a region of varying forms of government in which different city-states each had their own constitution (Howatson, 1989). Greece was united in language, religion and a certain sense of self, but each polis was its own political entity. The range of ideologies concerning what counted as "the good life" and what constituted a proper civilization varied remarkably. Within Ancient Greece one could find monarchies, oligarchies, tyrannies, and democracies. The two most powerful city-states at the time of Plato's *Republic* demonstrate this heterogeneity: Sparta and Athens. Sparta was by and large a military state being governed by two "kings," who served as the top military commanders. Most of the population belonged to the class of helots, who were servant slaves to the state. In order to maintain this political imbalance, the Spartan males formed a professional fighting force, the hoplites, and spent their youth training their bodies and minds to the art of infantry warfare. Being a hoplite was expensive and the training required was extensive, joining its ranks was then only open to the wealthy, reinforcing the social dichotomy. During the Peloponnesian War (431-404) Sparta and her allies roundly defeated Athens (Howatson, 1989). This defeat, by no means a forgone conclusion, humiliated Athens and had a profound effect on both subsequent political events and Plato's philosophy.

Athens stood in stark contrast to Sparta. The power of Athens was built not on a class of elite warriors, but on commerce and the navy which defended that commerce. Athens had developed a network of trade and allies across the Mediterranean (Ibid). Where Sparta rested on the strength of its infantry, Athens looked to its fleet of triremes. The triremes were the most advanced fighting ships of the ancient world and in close quarters relied on oar-power to maneuver and ram enemy ships. Sailors and rowers required much less individual equipment than Spartan hoplites, and so its ranks were open to a much broader class of Athenians. The reliance on such a broad base supported the need to govern through assemblage, public debate, and consensus-making; hence the more democratic form of governance. In the ancient world:

> The onetime power and prosperity of democratic Athens signaled a major political innovation. Coinciding with the rise of democracy in Greece came an increasing prioritization of oratory skills. For in the agora, where citizens met to decide upon the affairs of state, the majority needed to be persuaded of appropriate courses of action (Taffel, 2004, p. ix)

The political system drove the Athenian educational system. A more democratic city-state required an educational system aimed at developing the ability to reason, to bargain, and to persuade.

In Plato's time, however, "Greek education was pitiful: restricted to upper-class boys, it was in the hands of slaves, and taught no more than the three Rs, sport, Homer and the lyric poets, and the ability to play a musical instrument" (Waterfield, 2002, p. xiv). Herein lies the importance of the *Republic* (Plato, 380 BC/2008) to our topic: Plato maps out a radical alternative to the Athenian system of education in order to introduce great social reforms. He censors the role of the poets, replacing their study with that of philosophy, changes the relations of sexes, demotes the possession of material property, challenges traditional notions of parenthood, and even alters the religious calendar through the agencies of education. Plato apparently had an almost limitless belief in the power of education to shape an individual or a society, and like Counts, saw it to be "a force of great power" (1962, p. 62). On the way to creating his ideal polis Plato used education as a tool of great transformative power. However, an ideal implies perfection; once his ideal society had been attained, education would serve a distinctly conservative role. Any further change would only introduce imperfection.

The *Republic* (Plato, 380 BC/2008) is a complex work, with many layers and arguments. The key to understanding it is to bear in mind the central analogy developed at the outset, that Society is writ large what the individual citizen is writ small. "Morality can be a property of whole communities as well as of individuals" and it would be easier to examine the workings of morality "on a larger scale in the larger entity" (Ibid., p. 58: 369a). Plato's purpose was to show that, "Morality is worthwhile in and of itself for anyone who possesses it…whether or not it is hidden from the eyes of gods and men" (p. 56: 367d). The aim of the argument, in other words, was not to describe the perfect society, but to demonstrate that the moral man was the happiest man. Plato only created his famous polis as a sort of proof. Everything else in the dialogue is incidental to this central analogy and primary goal. For this reason, the *Republic* is not a manual on education despite all the rich insight regarding the purpose and power of education.

The guardians of the state received the lengthiest, and most thorough education on account of their grave responsibilities. Most of the discussion regarding education in the *Republic* therefore centers on these elite and it is here that we find here the most radical suggestions for the transformation of traditional Athenian society. At the heart of Plato's plan is the realization that, "Different people are inherently suitable for different activities, since people are not particularly similar to one another, but have a wide variety of natures" (Ibid., p. 60: 370b). It then becomes societies task, or that of those who govern, to help "fit" individuals to their station and discern the sort of education that is required. “The principle we established, and then repeated time and again… that every individual has to do just one of the jobs relevant to the community, the one for which his nature has best equipped him” (Ibid p. 140: 433a). The most audacious reforms were justified by his attempt not to transform individuals, but to perfect society as a whole. “We are not constructing our community with the intention of making one group within it especially happy, but to maximize the happiness of the community as a whole” (Ibid., p. 123: 420c). If this meant that the happiness or good of any individual within it, the part, needed to give way to the good of the whole, then so be it.

One of these radical transformation of Athenian norms deals with the education of women. Women in classical Athens led repressed and secluded lives. As Waterfield (2002, p. xiii) points out, “Respectable Athenian women would rarely be seen on the street; their job was to keep house and bring up the children.” In stark contrast, Plato held that, “Innate qualities have been distributed equally between the two sexes, and women can join in every occupation just as much as men, although they are the weaker sex in all respects” (Ibid., p. 167, 455e). Because of this notion, Plato proposed that women needed to be brought up alongside men. “If we are going to use the women for the same purposes as the men, we have to educate them in the same way” (p. 162, 451e). Plato’s push for equality between the sexes in education and training included training in the arts of war. As women were to become guardians, their education necessitated, “having women exercising naked in the gymnasia along with the men.” Compared with the standards of traditional Athens, such ideas must have seemed absolutely ridiculous! Even Socrates admitted, “A lot of our suggestions would seem ludicrous and outlandish if they became practical realities.” To which Glaucon, the other interlocutor adds, “That would certainly be thought ludicrous, as things stand today” (p. 163: 452b). Plato was not in a position of political authority; his were theoretical and philosophical perspectives, but how truly transformative and liberating such changes would have been!

Plato upended another aspect of Athenian society: the possession of material goods. In an aristocracy such as Athens, evidence of status came from the display of wealth in material possessions. How shocked his audience must have been to hear Plato claim, “Genuine guardians shouldn’t own houses or land or anything, but should be given their food by others, as payment for their guarding, and should all eat together” (Ibid., p. 179: 464c). A central criterion for the Guardians was their ability to see wealth, in its greatest form, as the freedom from material things; money, real-estate, fancy clothes bespoke of lower appetites which belonged to the lower classes of society and were unworthy of true rulers. The refutation of private property extended to marriage for the elite of the polis, “There is to be no such thing as private marriage between these women and these men. Plato clarifies, “All the women are to be shared among all the men. And that the children are also to be shared, with no parent knowing which child is his, or child knowing his parent” (p. 170: 457d). To justify such a radical proposal, Plato asks the rhetorical question, “Could we describe anything as better for a community than something which binds it together and unifies it?” (p. 176: 462b). If even children and spouses were held in common, it gave every guardian the ultimate incentive to serve and protect the whole community, not just their own property.

Plato had even more surprises in store for his readers, seeking to transform not only sexual and marital norms, but even religious festivals. Socrates proposes that, “The main privilege and reward that any young men who are good at fighting or at some other activity ought to receive is the right to sleep with the women more frequently” (Ibid., p. 174: 460b). This would be done, “So that as many as possible of the children are fathered by this kind of person.”

To this end, the religious calendar would be rewritten. The state would "Institute certain holidays and religious ceremonies, during which we'll bring the brides and grooms together" (p. 173: 459e). Socrates, in the *Republic*, is not above hiding the truth from his citizens, since such actions might create jealousy among even the guardians. "The fact that all this is happening should be concealed from everyone except the rulers themselves, if the herd of guardians is to be as free as possible from conflict" (p. 173: 459e). Even to our own sensibilities, where women have a large degree of autonomy and sexual norms are generally relaxed and these suggestions seem radical. But, one must compare them with the actual state of affairs in aristocratic Athenian society to understand how radical and transformative they were for his audience. According to Waterfield (2002, p. xiii), the absence of well-to-do women from Athenian public life impeded, "the normal interplay between men and women which underpins a heterosexual society" and led in turn to widely accepted homoerotic affairs between boys and men, extramarital affairs by male slave-owners with their slave-girls, and generally loveless marriages.

If one bears in mind Plato's original purpose while contemplating his *Republic*, much begins to make sense which otherwise seems weird. Plato sought not to convince his contemporaries to construct his ideal city, but rather to win a philosophic argument about the benefits of living a moral, internally coherent life. Robin Waterfield, in his introduction to his translation of the text, sees the *Republic* as "Plato's main attempt" to reveal, "how an individual can fulfill himself, can attain happiness or 'live the good life' as a Greek would say" (Plato, 380 BC/2008, p. xvi). Plato was not concerned with creating a real, or even achievable society, but rather with revealing the benefits of morality. Gaps exist in Plato's description of the ideal state and its educational system precisely because it was designed primarily to serve as an analogy to the soul of a good person, not as a political how-to manual. Plato didn't bother to explain how every change would be made, but rather relied in a very general sense on the proper education of his elite. What he gave us thought is enough to indicate a radical re-envisioning of Athenian society through the engines of education.

Eliot's America

The second time-frame I have selected, the America of Charles Eliot's time, known generally as the early progressive era (1880-1914), was one of rapid social transformation (DeBoer, 1991; Kliebard, 1995; Urban and Wagoner, 2004). In contrast to the imagined system of education described in Plato's *Republic*, the school system of Eliot's day both recent and real. Three major social and cultural shifts were taking place: immigrants from Eastern and Southern Europe poured into the East Coast, rural Americans moved towards the cities, and industrialization continued to replace individual labor (Urban and Wagoner, 2004). According to this source by the end of the 19th century nearly half of all Americans lived in cities, the size and complexity of factories increased significantly, industries related to mining invaded rural areas, "visible extremes of wealth and poverty" appeared, and a "massive" flood of immigrants from "exotic" backgrounds arrived (Ibid., p. 160 and 210). Such shifts caused corresponding changes in the means and modes of employment for untold Americans, changes in the daily rhythms of family life, and even altered the makeup of America's school-aged population. According to Kliebard (1995), "Nineteenth- century society...was clearly in decline, and with the recognition of social change came a radically altered vision of the role of schooling" (p. 1). This new "vision" of schooling focused on both what students were taught and the way in which they were taught. "With the society in such a rapid state of flux, it should not be surprising that the matter of what we teach our children in school should also come under scrutiny" (p. 4). A great sense existed then of the need to transform public education to ensure America's youth were prepared to face to the new realities and able to preserve what could be of the previous era.

The views found in Eliot's writing form a nexus between the emergence of the newer philosophies of progressive education and social efficiency and the passing of the older ideologies of Humanism and mental discipline. As President of Harvard, Charles Eliot pushed for the university's modernization by introducing the elective system. As Chair of the Committee of Ten, he was esteemed by his peers as one of the nation's leading reformers of education. As an energetic writer, he has left behind a considerable corpus of thoughts regarding the transformation of American education. "Eliot...was the champion of the systematic development of reasoning power as the central function of the schools, and he recognized that much of what transpired in schools was simply unrelated to that" (Ibid, p. 9). Evidence of Eliot's philosophy will come from three of his works: *The Report of the Committee of Ten*, *The New Definition of the Cultivated Man*, and *Education for Efficiency* (the latter two published together in 1909). Given his stature in the educational world of his day, Eliot was something of a spokesman for his contemporaries, and he will be used as such in this essay.

In his book, *Secondary Schools at the Turn of the Century,* Theodore Sizer declared that schools were "a peculiar blend of tradition and change" (Sizer, 1964, p. 17). At the turn of the last century, tradition was represented by "classical education" as had been found in the Latin Grammar School as well as "useful studies" found in the common schools. Change was represented by "the quickening intellectual revolution caused by evolutionary doctrines and scientific advance, by vast demographic growth and shifts in the country, and by an altering labor market" (Ibid, p. 17). To meet these forces of change schools needed to transform themselves and their students. The pressure was towards a more "efficient" education. "It was social efficiency that, for most people, held out the promise of social stability in the face of cries for massive social change" (Kliebard, 1995, p. 77). As the 20th century progressed, the notion of efficiency in education evolved ever more towards something resembling industrial factories.

Published in 1893, the *Report of the Committee of Ten on Secondary School Studies* reflected both the desire of Americans to change their educational system and their inability to do so quickly enough. The product of a society in the midst of self-transformation, it is a considered a seminal document with "a profound influence on American education" (Sizer, 1964, xi). For fifteen years after its publication, the *Report* "served as gospel" for those seeking to rewrite the curriculum of "the burgeoning high schools" (Ibid, xi). While the immediate impact of the *Report* was significant, that impact was of relatively short duration. "Just 20 years after his vision of educational reform was proposed," it seemed the report "had been written a hundred years earlier" (Deboer, 1991, p. 37-38). At its publication, the *Report* marked "a moderate departure from the traditional curriculum of the nineteenth century" (Kliebard, p. 14). As the new century unfolded, however, increasingly it symbolized, "The failure of the schools to react sufficiently to the social change and the changing school population" (Ibid., p. 13). The rate of cultural change during this early progressive period is precisely what makes its study so exciting. As education sought to reshape society, society was already transforming its notions of education.

The Committee of Ten saw many of their recommendations as being "of a radical nature," and yet at the same time they found their report, "distinctly conservative and moderate" (National Education Association [NEA], 1893/2012, p. 13). In other words, the committee was itself aware of its position between favoring the past and forging ahead. To address its work more effectively the committee broke up into nine conferences, each addressing a particular subject or set of subjects: Latin, Greek, English, Modern Languages, Mathematics, Physics & Chemistry, Natural History, History, Geography. Most American secondary schools at the time still used a very traditional curriculum with the classical languages (Greek and Latin) and Math forming the core of a good education. These three subjects only represented a third of the conferences. The other six conferences, "Ardently desired to have their respective subjects made equal to Latin, Greek, and Mathematics in weight and influence;" yet as, "many teachers and directors of education felt no confidence in these subjects as disciplinary material" (Ibid., p. 13), this was a considerable challenge. For the recent "modern" subjects, the first transformative task required the rebalancing of the secondary curriculum. How far they had to go is brought home by use of the term "disciplinary material," referring to a view of education as a mental training akin to training in gymnastics (a very conservative view indeed).

A second transformative change recommended by the committee was the admission that secondary education must offer more than college preparation. "The secondary schools of the United States…do not exist for the purpose of preparing boys and girls for colleges," but rather they were "to prepare for the duties of life" those students who showed themselves "able to profit" from an extended education (Ibid, p. 51). The solution lay in a choice of paths towards high school completion. The committee recommended offering four courses for high school completion: The Classical, the Latin-Scientific, the Modern Languages, and the English program. The establishment of these four paths allowed students to select the education best suited for their interests and needs. At the same time each path would or could serve the traditional purposes of college preparation and admission.

Furthermore, the committee felt quite strongly that while students should choose which path to pursue yet within that path, as long as students chose to pursue it, all students would receive the same instruction. “Every subject which is taught at all in a secondary school should be taught in the same way and to the same extent to every pupil so long as he pursuits it, no matter what the probable destination of the pupil may be, or at what point his education is to cease” (Ibid., p. 17). Such comments build the sense of the Committee as breaking away from the traditional ideology or conception of education and working to modernize the American curriculum. Rather than a forerunner of tracking by ability, these four courses were an attempt to provide students with a chance to customize their secondary education. It was also a compromise between maintaining some semblance of the former “common school” experience and evolving a more efficient system which addressed the growing pressure to offer a more “practical” education that catered to student interests.

Eliot’s own thoughts on the purpose of education become even more clear in the work of which he was the sole author. While the final product bore Eliot’s stamp, the *Report* really was the outcome of a committee drawing upon the work of the several conferences. In the papers he wrote alone, it becomes very apparent how hard Eliot sought to liberate education from its deep and rich tradition, a tradition in which he himself had been steeped and was unable to completely break away from. As Chairman of the Committee of Ten, Eliot had sought to rebalance the American curriculum to include the “modern” subjects on an equal footing to the venerable classics curriculum. Trained as a Chemist, Eliot saw science and technology as a force which was improving the lives of Americans around the country; it was a force which could not be ignored. Yet, as a graduate of Harvard and a member of America’s education elite, Eliot had also been trained in the very classical tradition which was becoming increasingly dated.

The New Definition of the Cultivated Man (Eliot, 1909b), represents Eliot’s attempt to preserve the “cultivation” of a man (or woman) as the ideal of education, yet at the same time describing exactly how that notion needed to evolve if it were match the rapidly changing world. The reason for the "profound modification of the ideal of cultivation," Eliot envisioned was growing impossibility for anyone to have "a knowledge of everything--not even a little knowledge of everything" (Ibid., p. 45-46). Eliot felt it had become impossible to know "even a little" of everything because of the progress of the natural science. "All thinkers agree that the horizon of the human intellect has widened wonderfully during the past hundred years, and that the scientific method of inquiry…has been the means of widening" (Ibid., p. 36). Such an explosion of knowledge necessitated the switch from rote learning of facts to mastering the new method of scientific inquiry. "This method has become indispensable in all fields of inquiry…and therefore intimate acquaintance with it has become an indispensable element in culture" (Ibid., p. 36). If one could not have a knowledge, even a little knowledge, of every important topic, one needed to learn how to evaluate the value of information as one encountered it. If no solution was readily available, then one needed to find one's own solution.

Science was the great addition to Eliot's new definition of the cultivated man, not only because of its method, but also because of its force in shaping the natural world. Science had become "a fundamental necessity in liberal education," because it had "transformed the world as the scene of the human drama" (Ibid., p. 37). It offered not only new ways of pondering the realities of the world; science had also led to practical advancements, advancements that any cultivated gentleman ought to have a decent understanding of. Eliot argued given this success even, "The most convinced exponents and advocate of humanism now recognize that science is the paramount force of modern, as distinguished from the antique and the mediaeval spirit" (Ibid., p. 37). When he came to compare the creativity of scientists and engineers with those of poets and other literary types, Eliot waxed extremely eloquent:

> Contrast this [literary] kind of constructive imagination with the kind which conceived the great wells sunk in the solid rock below Niagara that contain the turbines, that drive the dynamos, that generate the electric force that turns thousands of wheels and lights thousands of lamps over hundreds of square miles of adjoining territory (Ibid., p. 50).

Eliot then continued on about the invention of radio transmission, “Or with the kind which conceives the sending of human thoughts across three thousand miles of stormy sea instantaneously, on nothing more substantial than ethereal waves” (p. 50). As such scientific creativity involved “no crime, cruelty, or lust,” it was in some ways even preferable to the literary sort.

Eliot did not completely abandon the Humanist tradition in which he was brought up. Rather he sought to transform humanism from its reliance on the authority of ancient tradition into an emphasis on character development. According to Eliot, the cultivated modern man was, “to be a man of quick perceptions, broad sympathies, and wide affinities; responsive, but independent; self-reliant, but deferential; loving truth and candor, but also moderation and proportion; courageous, but gentle; not finished, but perfecting (Ibid., p. 34). Such moral virtues as the purpose of education is no great departure from those outlined by Aristotle thousands of years earlier in his *Nichomachean Ethics.* Similarly, when it came to the question of what small portion of humanity’s infinite store of knowledge ought to be taught, “The answer must be: those which enable him, with his individual personal qualities, to deal best and sympathize most with nature and with other human beings” (Ibid., p. 45). Science, it seems, was able to lead one’s mind in rational investigations and in solving difficulties, but it was the humanities which imbued the individual with the character of cultivation:

> Let us remember that the moral elements of the new education are individual choice of studies and career among a great, new variety of studies and careers, early responsibility accompanying this freedom of choice, love of truth, now that truth may be directly sought through rational inquiry, and an omnipresent sense of social obligation (Ibid, p. 55).

Eliot favored then a form of education which developed the moral aspects of the individual or making a person more completely human. One finds in this enumeration of a modern gentleman's character traits Eliot's loyalty to humanism. A modern liberal education, however, did not come from memorizing the teachings of ancient authorities but rather it involved learning to liberate one's self through rational, critical examination of facts.

In *Education for Efficiency* (1909a) Eliot expounded the virtues of efficiency in education. In his view, efficiency meant "effective power for work and service during a healthy and active life" (Eliot, 1909a, p. 1). Two ingredients here worth noting: the purpose of education as benefiting society, reflected in "work and service," and the mention of, "a healthy and active life," which points to the purpose of education as benefiting the individual. Eliot here straddles the fence, attempting to bridge the increasing demands of society and expediency with the traditional aims of education as a development of the individual. As one reads more of his work, however, one comes to clearly see Eliot as a champion of education which liberates the mind and frees the individual to enjoy the most passionate life possible. For one thing, Eliot argued that education ought to be widespread, with as many enjoying its fruits as possible. As he wrote, “Every individual…should desire and strive to become possessed” of this effective power, and that the “training and development” of it ought to be the goal of “the education of each and every person.” One sees in these last quotes a key aspect of Eliot’s conception of education, that any good education was a public good.

Known as the architect of Harvard’s elective system, Eliot did not advocate for a common curriculum, but rather saw a common purpose in all good education, and desired that such an education be accessible to every American. Unlike the later proponents of social efficiency, Eliot felt that passion and imagination were key components of any real learning. Even an efficient education “must not be materialistic, prosaic, or utilitarian.” Quite to the contrary, it needed to be “idealistic, humane, and passionate,” or it would fail to achieve its aim of empowering the individual (Ibid., p. 29). Eliot knew the importance of enthusiasm. Bored students did not learn their lessons well, whereas, “A good passion can make ordinary talents extraordinarily effective.” Maintaining an individual’s enthusiasm extended beyond the classroom for, “A life without a prevailing enthusiasm is sure not to rise to its highest level. These private enthusiasms or devotions are fortunately almost as various as are the characters of men” (Ibid., p. 27). Eliot found pluralism a virtue and a strength. The variety of passions among individuals, rather than hindering the efficiency of schools enabled a society to possess the needed variety of occupations and professions each filled by people who cared. If workers cared about the work they did, they would perform that work to the best of their ability.

Given its emphasis on idealism and emotion, what made this sort of educational philosophy efficient? Eliot declared that an educational system which developed a person’s effective power, “will thereby increase the total national productiveness and efficiency. It will also add greatly to the public happiness” (Ibid., p. 9). From his perspective, “It is not the cheapest labor that is the most profitable, but the best fed and lodged, the healthiest, the most intelligent and the most ambitious." Eliot espoused liberating and transformative education for all because such education would maximize the effectiveness of members of every level of society. The purpose of good and true education was to unleash the individual's passion and ability to sustain concentrated thought:

> The will power of the individual is the taproot of all his growth in character and efficiency. Authority curbs the will power of the individual; liberty gives it play and exercises it. Therefore, the training of the will to the wise use of liberty is the great means of developing individual strength of character and national greatness (Ibid., p. 22).

Even members of the working class would contribute more to society if their innate abilities and desires were heightened by good schooling. A decade or so later, John Dewey (1916) would write the purpose of good education was, "To secure from each individual his fair contribution to the general well-being and see to it that a just return is made to him" (p. 253). As Dewey would echo Eliot, so in Eliot one finds strong echoes of Rousseau, and from there back to Plato: the goal of education is to teach people how best to use their liberty. Good education is transformative education which liberates the minds of its students, and such education is not only in the best interest of the individual, but also indispensable to the welfare of the nation or society which provides it. It is the sad fact that, so few educational systems achieve this end, which returns us to the claims of G. S. Counts.

Lessons to be learned

As Counts realized education can be put to many ends. And yet it in all societies education serves both as a transformative and conservative force, sometimes simultaneously and sometimes more-or-less alternatingly. Plato recognized the power of education in the *Republic*. In this dialogue a radical new society arises with the transformative force being the educational system. Radical in its transformative phase, Plato intended his society to become conservative once established. John Dewey (1916) recognized this:

> Although [Plato's] educational philosophy was revolutionary, it was none the less [sic] in bondage to static ideals. He thought change or alteration was evidence of lawless flux; that true reality was unchangeable. Hence, while he would radically change the existing state of society, his aim was to construct a state in which change would subsequently have no place (p. 105).

Plato's *Republic* was a philosophical exercise in arguing that morality is inherently worthwhile, not just for its consequences, but in and of itself. This first frame of reference was chosen for its enduring significance to the philosophy of education. While education was used as a vehicle to demonstrate an ideal state in which morality reigned supreme, this was not done to develop a new system of education, but rather to develop Plato's analogy between the city and the citizen on the way to winning his argument with Thrasymachus, Adeimantus, and Glaucon.

My second frame of reference, the early progressive era, was once very real and alive. It serves as a historical lens to witness the same phenomenon: the degree to which education is transformative or conservative varies with culture and context. During this period Charles Eliot sought to change the existing school system to better serve the unfolding needs of its students.

He espoused an efficient education, by which he meant a liberation from authority, giving people the self-awareness and vital energy, they needed to be effective members of society. Such an education was intended as means of social transformation by leading people to secure the best possible future for themselves and their society. Efficiency was not yet bereft of creativity and passion in Eliot's views as his own writings have shown.

In later decades influential individuals such as Bobbitt, Charters and Snedden would even call for the "elimination of the conventional subjects" (Kliebard, 1995, p. 98), in the name of promoting efficiency in education still further. "People, after all, should not be taught what they will never use. That was a waste" (Ibid., p. 85). As the rate of social change increased, the educational system became more a tool for social conservation and less a means of social transformation. While the progressive period is much closer to our own, with norms and values easier to recognize, yet it too is now only accessible through text and artifact. The enduring value of textual studies such as this are in the details revealed as well as in the general patterns elucidated. Confined to either the realm of historical or philosophical recollection, a parallel exists between the two frames I have chosen. Neither can be inspected, visited, or questioned as a contemporary system of education could, but both provide deep and informative truths regarding our current circumstances.

Section Summary

In this section, two educational systems that of Plato's *Republic* and of Charles Eliot's America were compared. Plato's writing, especially his *Republic* served as a source of inspiration for educators like John Dewey, who found therein the idea that society is best organized when all its members are doing what they are best suited for. Plato's republic however was autocratic; the educational system of Charles Eliot was intended for a democracy. In appearance both were very distinct, and yet both were intended to maximize the social benefit of individuals to their society. These two systems were compared in order to add further color to our painting of late 19th century American education. The theme of educating the individual for social benefit is at the heart of formal schooling and is discussed further in the next chapter. In the next section of this chapter we will look at some of the broader issues facing formal education during our period of interest.

Growth & Technology: America's population, cities, schools and inventions

In this section we look at some of the broader social changes which were concurrent with the evolution of physical science education in America at the secondary level. This section continues the analysis of the period which was begun in chapter one. It begins by looking at the changing demographics of the country as a whole before looking at some of the major disruptions in technology that coincided. It then traces how high schools arose to fulfill a social sorting and credentialing service and how increasingly science became seen as a new form of social authority and domination. A statistical dive is taken into the issue of school retention before the perceived need for the reorganization of schools in the early 20th century is revisited.

Changing Demographics

Between the years 1860 and 1940 the American population rose from under 40 million to over 120 million (US Bureau of the Census, 1949). This means in the eighty years from the Civil War and the age of the railroad to the start of the Second World War and the age of the airplane the American population tripled (Figure 1). Such growth exerted tremendous transformative pressure on social institutions and customs. More people means more available man-power to complete major infrastructural works but also more competition.

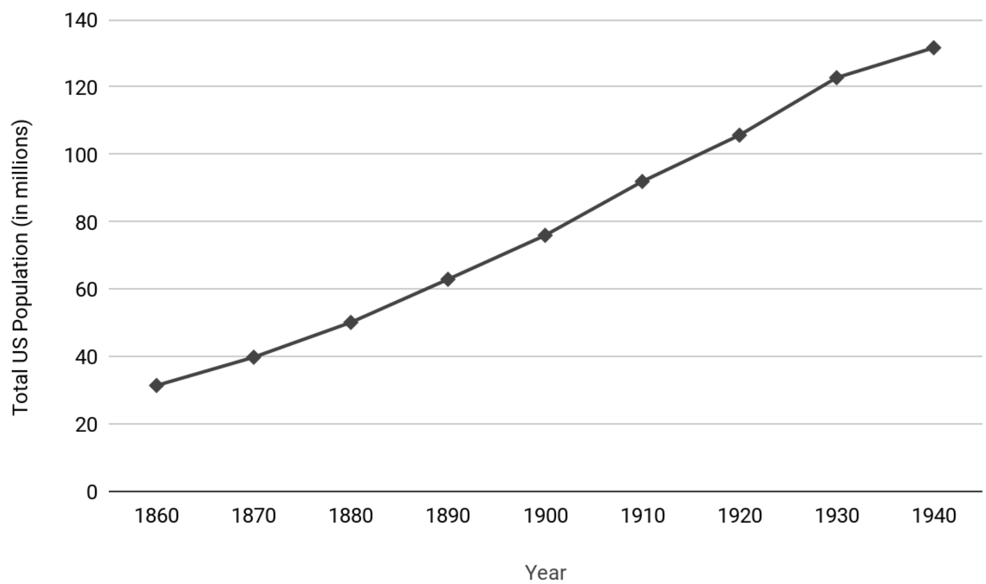

Figure 1. Growth of US Population: 1860-1940 (Data from US Bureau of the Census, 1949)

This population growth coincided with a massive growth in cities (Figure 2).

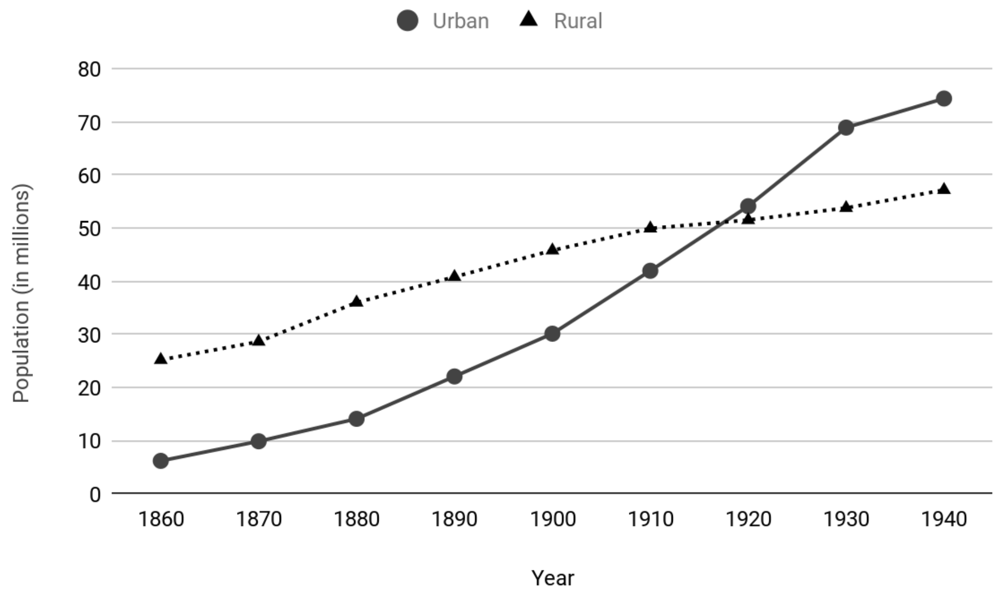

Figure 2. Growth in Urban and Rural US Populations Compared: 1860-1940 (US Bureau of the Census, 1949)

In 1860 fewer than 10 million Americans lived in urban areas. Eighty years later that number had risen to over 70 million, a more than seven-fold increase! While the rural population continued to increase during the same period, rising from under 30 million to over 50 million, its growth was more nearly linear compared to the exponential growth of urban areas. The US had gone from being a rural nation in which three times as many people lived in the country side to one dominated by an urban majority. Such changing demographics exerted strong pressure on social systems including schools to change the way they did business.

Technological Progress

The rise of America's cities corresponded with its growing industrial might. The growth of cities was fueled by swelling numbers of factories and centers of manufacture which were hungry for human capital, individual wage laborers willing to toil in the processes of production. The story of American steel production gives a sense of the tremendous growth in factory output during this period (Figure 3). According to the US Bureau of the Census (1945), in 1867 the total production of steel amounted to only 19,643 long tons. By 1907 the country was producing 23,362,594 long tons of steel. This is more than a thousand-fold increase in only forty years. This single commodity, steel, can be taken as an indicator of American industrial as it lay at the heart of building ships, railroad tracks, cars, factories and later airplanes.

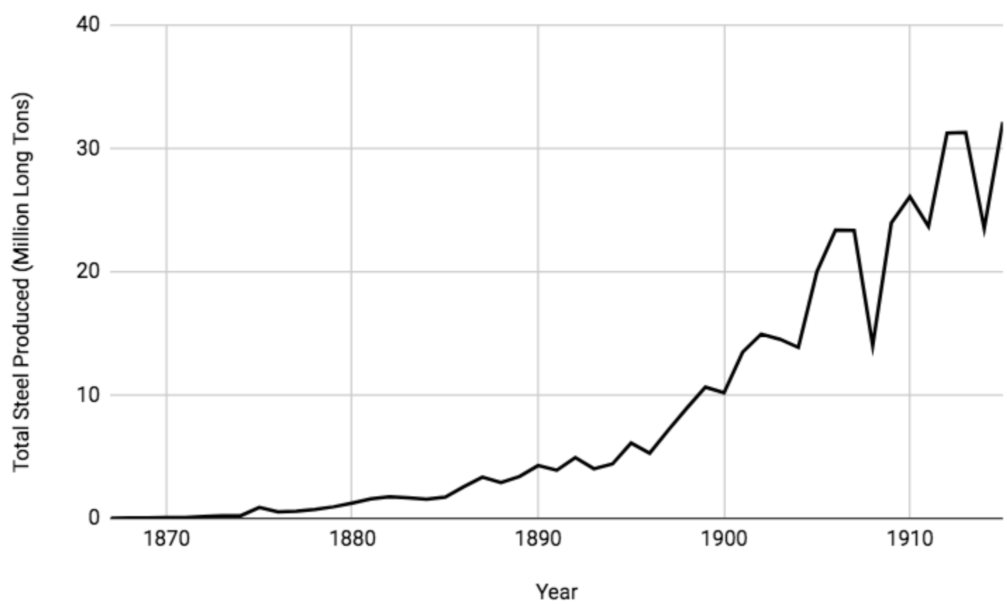

Figure 3. Growth of Total US Steel Production: 1867-1915 (US Bureau of the Census, 1949)

But it wasn't just the scope and scale of industry which was changing the face of America in the late 1800s and early decades of the 1900s; technological advances made much of the growth possible. Technological developments build off one another, each creating products which can be used to push further forward. Bessemer developed his famous process for converting iron into steel in 1856, which would allow American to enter the Age of Steel (Bachman, 1918). In 1876, Alexander Graham Bell received his patent for the telephone and introduced it to the world at the Centennial Fair that same year. By 1882, Edison had developed an electrical locomotive and placed it on display at his Menlo Park laboratory. In 1901 Marconi first succeeded in transmitting a wireless radio signal. In 1903 the Wright brothers made their first powered flight which began the American age of the airplane. Such visible technological advances not only stimulated the common imagination but had direct practical applications in business. The number of “Electricians and powerstation operators” recorded by the US Bureau of the Census (1945, p. 66) jumped tremendously from 396 in 1870 to over 119,000 in 1910, revealing the state to which America was becoming electrified.

Rise of science as form of authority

Theodore Sizer (1964) in *Secondary Schools at The Turn of The Century* described how rapid progress in experimental science led to greater trust in the rational expert and shook clergy's claim to revealed truth. The rate and strength of impact of this change differed regionally but according to Sizer, “Those sections of the country most touched by the rapid expansion and growth were the most affected” (Ibid., p. 10). As people witnessed the transformative power of technology, science gained in authority. This was especially true in colleges and universities where “the rapid acceptance of Darwinism and Spenserian ideas by scientific leaders” was “most striking” (Ibid., p. 10). As cities grew both in size and complexity, the demand for highly educated individuals increased leading to a rise in university enrollment, which continued to feed to rise of science as a form of authority. Sizer explains how, “the scientific spirit gave authority to the disciplined inquirer as a source of truth" with the effect graduates of Harvard and other colleges "replaced the clergy as the sources of knowledge" (Ibid., p. 11). These graduates, regardless of their scholarly focus, were increasingly well trained in experimental science.

The rise of science as a form of authority generated its own demand for more experimental work, first at the University level and then at the secondary level. Laboratory instruction increased as, "scientific methods resulted in the call for laboratories planned essentially for teaching" (Sizer, 1964, p. 11). As laboratory classes caught on at the tertiary level, textbooks aligned with the new method began to be produced. Even Harvard's own "President Eliot, a chemist, prided himself on producing what he considered the first textbook in chemistry using the laboratory method" (Ibid., p. 12). This surge in scientific interest came to impact high schools and lead to a broadening of the curriculum. "Darwinism and scientific thought, then, not only raised the academic man to a more prominent place in society, but also provided pressure for more studies, more disciplines, to be offered in the schools" (Ibid., p. 13) and so "the demand for schooling of the city dweller coalesced with the notions of the new scientific thinkers" (Ibid., p. 14). From Sizer's perspective, at the end of the 19th century, "change was represented by the quickening intellectual revolution caused by evolutionary doctrines and scientific advance, by vast demographic growth and shifts in the country, and by an altering labor market" (Ibid., p. 17). Thus, the social forces of population growth, urbanization and industrialization merged with Darwinian thinking, technology and a rising tide of secularism to pressure changes in the educational system. While Sizer sees these pressures coming to a head in the work of the *Committee of Ten*, we will look further back in Chapter 4 to see what this changed looked like at on a smaller, finer scale.

The Rise of High Schools

Before high schools came to dominate in the 20th century, there were two traditions which exerted a strong influence on later secondary education: the Latin grammar school and the academy (Sizer, 1964). The Latin grammar schools focused on the classical-humanistic tradition preparing a few students for acceptance into the university, and academies emphasized more practical education such as book-keeping and surveying. Despite the existence of these two forms of secondary education, American high schools grew neither out of the grammar schools nor the academies but rather out of an expansion of the common (elementary) schools. High schools formed as additional years were added to and expanded the common school curriculum. "Algebra was added to arithmetic. English study followed the alphabet", as Sizer put it (Ibid., p. 5). This slow creep upwards satisfied society's demands for a time, but as enrollments continued to swell, the high schools struggled with which tradition to draw from, the classical or the practical. While were these larger schools to prepare students for: college or career? Should they offer a practical curriculum, or a classical one? The work of sorting out the confusion and attempting to standardize the curriculum gave impetus to the work of the Committee of Ten.

During the middle of the 19th the array of secondary education institutions was bewildering. As the historian Theodore Sizer has pointed out these institutes, "varied markedly in terms of size, quality, course offerings, and even aims" (1964, p. xiii). This confusing multitude could be loosely sorted into three main types: Latin grammar schools, academies, and high schools. Yet while some distinctions did exist the neat classification into three distinct groups gives a false sense of uniformity; there was difficulty in discerning what constituted "college work" and a troubling tendency of some state superintendents to combine, "colleges, academies, and high schools together in their statistical summaries." However, by "the close of the nineteenth century a national system of education" began to evolve as a consequence of society demanding "a ladder of formal schooling from grade school through university" (Ibid., p. xii), leading to a tremendous growth in schools and enrollment.

The rising number of high schools across the country between 1850 and 1890 is seen in Figure 4. The data was taken from statistics cited in *NEA: The First Hundred Years* (Wesley, 1957). The graph reveals the tremendous rate of growth between 1880 and 1890 during which time high schools increased by the same number as they had in the previous thirty years combined, more than doubling in ten years.

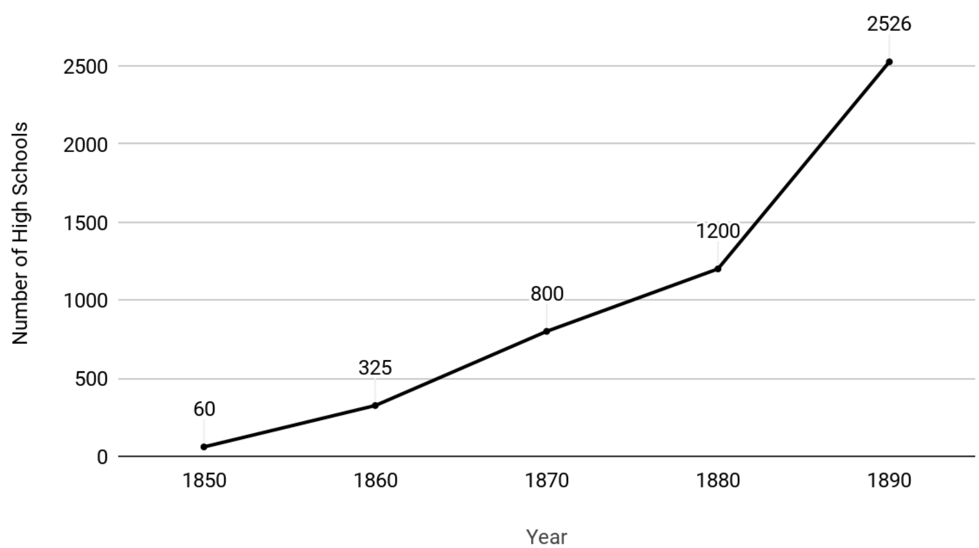

Figure 4. Growth of US High Schools: 1850-1890 (Data from Wesley, 1957).

The need for more school was pressing as society demanded "a ladder of formal schooling... which an ever-increasing percentage of Americans would climb" (Sizer, p. xii). Prior to 1890, secondary schools were seldom used as a "social sorting device" because so few youths attended.

As urbanization progressed, the more concentrated communities were able to raise the funds required to support public secondary education, and schools grew. The opening of the market allowed "men bent on success" to realize their desire to climb up the social ladder, and schools increasingly came to help sort out those who had such "ruthless ability to succeed" from those who didn't (Ibid., p. 9). The diploma came to be valued more as a symbol of competitive ability than for a measure of academic attainment. Sizer finds the importance of the Committee of Ten's *Report* in its function as the first attempt to bring order to a growing system of schools.

The number of students attending secondary schools in 1893, was still very limited both in absolute terms and as a portion of the relevant age group. In the decades which followed, this changed rapidly. Wesley identified a dramatic acceleration of high school enrollment beginning in the 1890s. By 1920, student enrollment saw more than a five-fold increase from 1890 (Figure 5). DeBoer, using data taken from the National Center of Education Statistics (1981), points out only 6.7% of 14- to 17-year-olds attended secondary school in 1890; thirty years later, this percentage had jumped to 32.3% (1991, p. 39). The growth was even more impressive in real numbers, swelling from 360,000 to 2.5 million. Such a rapid rate of growth must have put severe pressure on the school system to change the way it operated.

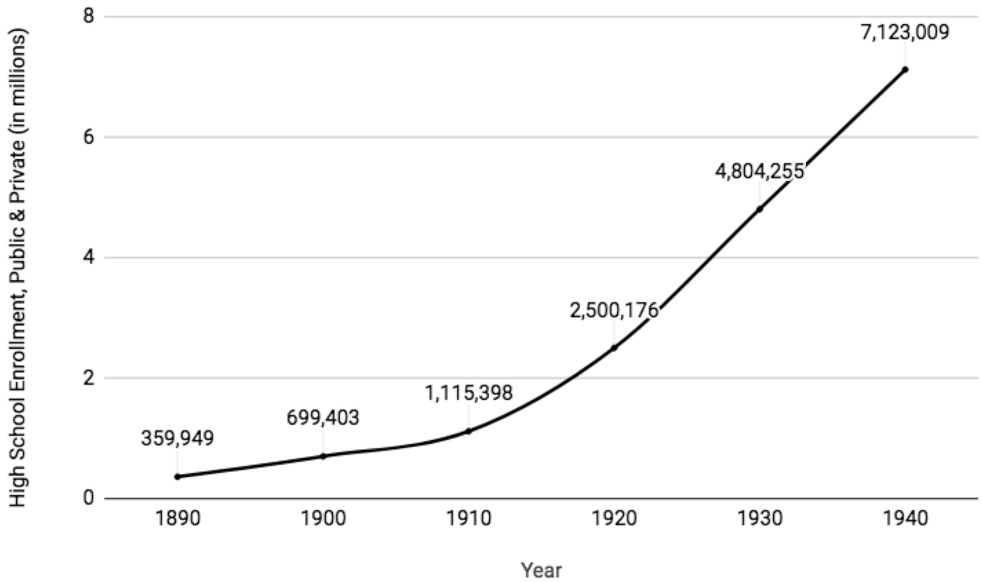

Figure 5: Acceleration of High School Enrollment: 1890-1925 (Data from Wesley, 1957)

The Committee of Ten recognized that the students served by secondary schools were a small yet important group. It was the group's importance to the nation that made it worthwhile for a large number of leading educators to meet in conferences to discuss what this age group ought to be learning. Towards the end of the 19th century Americans were beginning to realize the need for a "practical education" given that the world was "becoming dominated by science, technology, and industry" (DeBoer, 1991, p. 2).

The ascendancy of laboratory approach was at least in part also due to the group's small size. As a percentage of their age group, high school graduates were a very small minority in the 1890s (Figure 6). The laboratory method put an emphasis on students learning from actual manipulations of scientific equipment and conducting investigations rather than from books. In theory at least, it was an attempt to shift instruction away from sheer memorization and towards student comprehension of scientific ideas. In practice, it was a pedagogical method requiring close supervision of students by an expert instructor, conditions which would become difficult to maintain as schools and classrooms swelled.

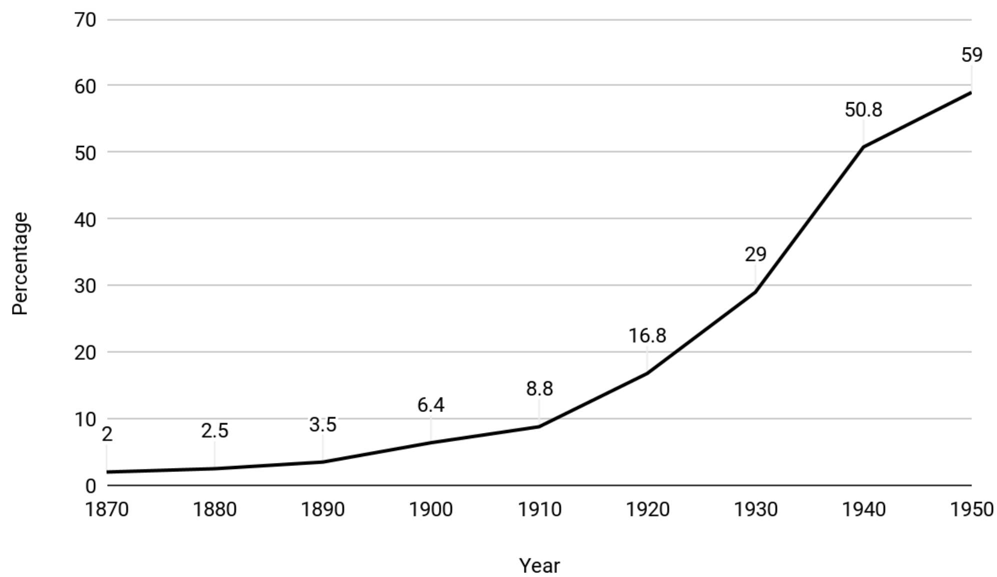

Figure 6. High School Graduates as a Percentage of 17-Year-Olds, 1870-1950.

(Statistics Adapted from Green, 1997).

The Need to Reorganize

As early as 1895, Harris realized the need for schools to grow and expand. His purpose was, in part, to help school superintendents or principals "to lay out the plan of a new system of school organization which promises to furnish a framework on which the schools under your charge may grow to an indefinite extent," (Harris, 1895, p. 8). However, with the growth of schools came increased concern about the number leaving before graduation. By 1920, well after the scope of this dissertation, this drop-out rate became a real concern. A Commission on The Reorganization of Secondary Schools was formed and published a report in 1918 charging that, "Failure to make adjustments when the need arises leads to the necessity for extensive reorganization at irregular intervals. The evidence is strong that such a comprehensive reorganization of secondary education is imperative at the present time" (NEA, 1918, p. 7).

Their report was entitled, *The Cardinal Principles of Secondary Education,* and divided its evidence for reorganization into three categories: changes in "society," "secondary school population," and "educational theory." Part of the evidence cited was the failure of most students to complete high school, with statistics given regarding the typical fate of students. These statistics were visualized into the following graph (Figures 7) and led among other things to a call for universal compulsory education to the age of eighteen.

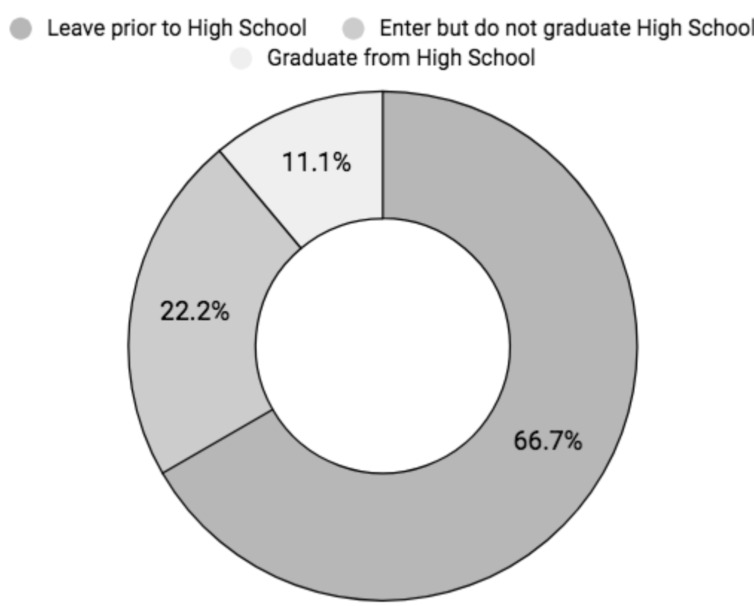

Figure 7. Fate of Students Entering 1st Grade (Data Adapted from NEA, 1918)

The call for universal secondary education by the NEA in the Cardinal Principles of Secondary Education coincided with a change in focus issues of student engagement. The Cardinal Principles put much less emphasis on academic rigor, and much more on the social purpose of public education. The last category of the report *changes in educational theory* was further divided into the following: the recognition of "individual differences in capacities and aptitudes among secondary-school pupils," the need for "reexamination and reinterpretation of subject values and the teaching methods with reference to 'general discipline,'" acceptance of the "importance of applied knowledge," and the incorporation of "continuity in the development of children." By 1918, the focus of educational reform had shifted from curriculum to the student, to their nature and to how they learned best.

Section Summary

In this section we have examined the changing demographics of the United States resulting from increasing urbanization, industrialization and immigration. This changing landscape created social pressures on schools to adapt to the needs of its changing times. One of those changes we will see in Chapter Four was towards a physical science curriculum which encouraged students to act as investigators. The goal was to teach students how to measure, record and experiment so that they would enter the workforce as useful employees able to tinker in factories to improve the industrial systems as well as repair and maintain machines. Society wanted people who not only knew what was going on but could get actively engaged in the way Charles Eliot described in the preceding section.

Chapter Summary

This chapter sought to build up the scholarly context within which the findings discussed later in chapter four can be interpreted. The chapter first reviewed some of the relevant literature regarding the history of education, then discussed why science education matters and how the future is a consequence of past actions, which was followed by a discussion of current directions in the history of science education. Following this, we compared two very different educational systems, that of Plato's *Republic* and Charles Eliot's America in order to how education serves those in political power. The portrayal of Eliot's America was also a precursor to the narrative analysis in chapter four. The final section of the chapter focused on the social forces of change which would pressure schools to adapt in the late 19^{th} and early 20^{th} century. The next chapter will discuss my theoretical approach to writing history by going into my positionality on the topic, my perception of schooling as both a social good and historically a means of social control, followed by a deeper look into my methodology.

CHAPTER 3. METHODOLOGY – APPROACHES

In this chapter I discuss my approach to history, the challenge of interpretation, and the task of writing. The purpose is to share with the reader information regarding my background, my conception of schooling and the purpose it serves, and my notions regarding the task of history so that my findings may be better interpreted. I begin with my positionality, or an attempt at describing how my personal biography intersects and interacts with my research topic. This is to help the reader understand not only my interest in the topic, but how it predicts which aspects of that topic I chose to focus on and what I left unsaid. That which is not spoken is sometimes as loud as that which is, especially in telling tales of the past and seeking to make sense of human experience. The second section examines my view of schooling and how it has played out in the United States. This is far from a comprehensive analysis or thorough historical investigation; the section is merely meant to help the reader understand the philosophical framework I apply in interpreting my results. The third section discusses my view of the art and science of history writing as well as how I conceive the nature of my task in completing this dissertation on one episode in the history of science education.

Positionality

In this section I explain my positionality. Positionality refers to the way in which, "One's personal biography is often a source, an inspiration, and an initial way of framing a research question" (Marshall & Rossman, 2011, p. 61) and "the challenge is to demonstrate that this personal interest… will not preordain the findings or bias the study" (Ibid., p. 63). For this reason, I describe my background and how I came to this topic. I acknowledge that as a physics teacher, I approach the discussion as an insider, yet must also confess that I only studied physics for one year at the University of Washington. I therefore feel a strong kinship with the teachers discussed by the textbook authors and the educational elites who wrote about what must be done to improve physical science education. There is a pain that comes with knowing I will never be the transformative physics teacher who can set students' worlds on fire but having been in the classroom I know first-hand the challenge in trying to do so.

As Saldana (2015) puts it, the lens, angles, and filters through which one views life determines how one perceives and interprets the world. Understanding a scholar's approach to their research allows us to assess their work more fully. It seems well therefore to address some methodological considerations, including my positionality and my understanding of the historian's task, before beginning the historical narrative and analysis in the next chapter. A large part of my positionality reflects an insider's perspective. Science was an early draw; it was always the class I felt most successful in and the one I understood best. For most of my time in college I saw myself as a science major. Only during the second half of my stay did I discover my fascination with the history of science, the story behind the present. The University of Washington awarded me a dual-degree in Biology (BS) and History and Science (BA). My undergraduate research efforts led to two scientific publications and a senior thesis based on archival letters of a British naturalist. After returning to Hawaii, I obtained certification in secondary science education (PBCSE) and then a master's degree (M.Ed.) from the University of Hawaiʻi at Mānoa.

For the past 6 years I taught science in the Hawaii Department of Education (DOE) and am now the science Department Head and Instructional Coach. As such I now frequently visit the classrooms of other teachers. This provides me with the opportunity to observe and reflect on a variety of teaching styles as I consider how best to support my teaching colleagues. While in the classroom, I taught nearly the full range of high school courses: physical science, physics, chemistry, biology, marine and environmental science. Through after-school STEM programs such as Robotics, Ocean Bowl, and Science Olympiad, I have worked with students in informal settings, allowing me to see them work in less choreographed settings. These experiences have all shaped my thoughts regarding what constitutes effective pedagogy.

At the heart of my dissertation is a desire to learn more about past practices in teaching science. My interest in the history of science education began with a presentation I made on J.T. Rudolph's (2005) *Epistemology for the Masses*. Rudolph's article traced the history of the scientific method with an intoxicating blend of broad insight and specific detail. One felt as if suddenly everything one did made sense. Afterwards I understood why I struggled teaching the scientific method as a set of five pat, straight-forward steps: question, hypothesis, experiment, analysis, conclusion or revision. As Harvard Professor J. B. Conant (1945, p. 158) remarked in his discussion of his *General Education in a Free Society*, "Nothing could be more stultifying, and perhaps more important, nothing is further from the procedure of the scientist than a rigorous tabular progression through the supposed 'steps' of the scientific method". Rudolph's research revealed how and why the complex work of practicing scientists became boiled down into a series of simple steps.

As a public-school science teacher, I have a direct, professional interest in public education and the issues that face it. Through my teaching assignments and volunteer opportunities I have been brought in close and constant contact with our youth and seen them contemplate the importance of STEM education. Although students regularly see the importance of technology, they largely fail to see its connection with the academic coursework they receive in class. The connection between the end products of scientific engineering and what they are learning in the classroom appears to be missing. I began asking myself, “Why do we have this problem?” Is it new? Has it been addressed before, and if so how and with what success?

I hope herein to have both established my credentials as one familiar with the public-school science classroom and familiar with its unique challenges. I have studied both science and history at the University level, published two scientific articles, authored an undergraduate thesis, taught at the high school level, served as a department head and as part of the school leadership committee. I came to this study seeking answers to persistent questions over how to improve secondary science education, hoping that a perspective from a greater distance would enable me to see more clearly what needed to be done. My limitations lie in my not being a professional historian, nor a professional physicist, and so not being able to approach this problem as they might.

Philosophy of Education

This section examines a fundamental question at the root of all education: what is its purpose? In it, I explore what other scholars and writers have thought about the role of education generally, and schooling specifically. I do so in order to advance the thesis that schooling in America functions to fit the individual to society, and that it has done so since its origins in colonial times despite a national ethos promoting the rugged, and free, individual. I begin by exploring the notion of schooling being a social good and compare this with the values expressed in two of our key national documents: The Declaration of Independence and the Constitution. I then trace the development of schooling from the colonial period into the new Republic and on into the early Twentieth Century.

Education arguably is the most important task facing a society. If one assumes a broad view of education as John Dewey did, then one sees initiating a society's young members into the, "interests, purposes, information, skill and practices of the mature members" without which, "the group will cease its characteristic life" as its true function (1916, p. 3). Education is the way a society both perpetuates itself and evolves to fit changing times. It is a combination of conservative and progressive forces working to ensure a groups perpetuation. Education works to maintain those social characteristics which function best in preserving the group, while striving to improve on those elements which impede the group's prosperity. Plato (370 BC/2008) in his *Republic* thus took great care in the education of his philosopher kings. If they were to lead his imaginary republic to perfection, they needed the best training of their day, both physical and mental, but the philosopher kings also to be set free from falsehoods and wrong social arrangements which Plate felt held back Athenians in the 4th century. The attempt to retain the best elements and improve on those retarding the growth and perfection of society can be clearly seen in Plato's scheme of education.

Today we perhaps have less faith in the *perfectibility* of society; asking questions such as "whose notion of perfection?" However, we generally retain the hope of improving society and in the U.S. much of this hope relies on the power of education. In 21st century America, science and the technology it has spawned, is arguably the most influential factor forcing our society to evolve. To sustain and improve our society, we must learn to integrate and manage technology, and the accompanying wealth of information which modern science has unleashed, into the fabric of our social norms. This needs to happen, and is happening, beyond schools as well, for schools are as Dewey saw, "relatively superficial means" of education (1916, p. 5). Also, it is a task involving much more than merely improving our understanding modern science; it requires improving our educational system using the full force of the humanities. Dewey acknowledged, that as our society becomes increasingly, “complex in structure and resources, the need of formal or intentional teaching and learning increases” (1916, p. 11), and so a discussion of our children schooling in science does need to be a part of the conversation.

In *A Place Called School* (1984), John Goodlad saw the American public and educators offering the following four purposes or goals for U.S. schools: 1) academic purposes or goals, 2) vocational purposes or goals, 3) social, civic, and cultural purposes or goals, and 4) personal purposes or goals. Several questions arise from this. Can all four purposes or goals be pursued maximally at the same time? Or do they conflict all of the time or, at least, some of the time? And if they conflict, does their simultaneous pursuit result in a bewildering incoherence that many find in American education? Or are there any other principles embedded within the liberal tradition that cut across all four which give a priority order and appropriate emphasis (or de-emphasis) to each of them? While the four purposes of education enumerated by John Goodlad are all worthy goals, it is not possible to pursue them maximally without some higher organizing principle to provide the appropriate priority order and emphasis.

Schooling as A Social Good

As with any simultaneous pursuit of multiple objectives, the goals must be organized with respect to some deeper first principle in order to minimize competition and conflict. In education this first principle is the perpetuation of the social group, through transmission of selected and adapted ways of doing, ways of thinking and ways of being and the knowledge and competencies required to engage in these ways. The four purposes brought forward by Goodlad may best be addressed in pairs: the first pair asks, “Education for whose benefit, that of society or of the individual?" the second asks, "Education for what end, academic or vocational?" Such a distinction helps clarify matters. As I argue below, the social imperative always triumphed over the personal in America's schools, even as society changed through time, while the priority of academic versus vocational goals were both subordinate to society's changing conception of what was most practical.

The principle of group perpetuation and evolution is the fundamental purpose of education. Following from this are principles which reflect the national disposition, dependent on the guiding ethos of the country. In the United States the utilitarian notion of the common weal, the greatest good for the greatest number, served as a social glue, expecting the individual to benefit society. The concept of personal liberty has therefore been largely suppressed by schooling, as schools emphasized the whole of society over its parts. Both notions, the common good and individual liberty are tied up in the founding documents of the country, and its liberal tradition. Yet a historical analysis shows that America's need to integrate diversity, to preserve peace and social stability, has directed the priority and emphasis of the four purposes mentioned by Goodlad. These four purposes do coexist in our schools, albeit with varying degrees of conflict. Such conflict, which manifests itself as the bewildering incoherence that many find in American education, arises when the deeper organizing principles are lost sight of, when reforms see trees rather than the forest.

John Dewey (1916) made the case in *Democracy & Education* that the fundamental principle of education is social survival, to renew and perpetuate a group. For, "in order to form a community or society" its members must share "aims, beliefs, aspirations, knowledge--a common understanding" (Ibid., p. 5), and this must be passed from one generation to the next. Without this transmission between generations, "the group will cease its characteristic life"

(Ibid., p. 3). Each generation would begin again, and in no way other than accident, resemble the traits of the previous generation. All the cultural capital would be lost, and there would be no continuity between successive generations. This does not ignore the necessity of change, as even social groups must evolve to fit changing environments and accommodate the results of progress and learning. Dewey recognized that as civilizations (or any social group) becomes more advanced, it must become increasingly selective in its transmission. “It realizes that it is responsible *not* to transmit and conserve the whole of its existing achievements, but only such as make for a better future society” (Ibid., p. 24). Education is then both a matter of stewardship, but also one of innovation.

So far, the answer has been quite clear: the fundamental principle guiding all education is to pass on the defining characteristics of the society while also shaping and adapting the group norms to meet changing times and current demands. This meant the social purpose of education came first and helped determine the relative priority of the other three: academic, vocational, and personal. But from here we pass beyond simple answers. We must begin making some distinctions, forcing our answers to become more specific. We are examining US schools in this question, which then begs the question what exactly should be transmitted? What are the defining “aims, beliefs, aspirations, knowledge” as Dewey called them, of the United States? Also, schools are not the whole of education; schools are but one part, the formal part, of an educative system. What part of the educative process is then apportioned to schools, and what functions are performed by other institutions, such as family, religion, or the workplace? Both of these considerations refine our analysis. Our response from here on takes a more characteristically American turn to examine formal schooling.

Education works to create continuity but has built in flexibility. Individual teachers choose their words and do so while interacting with students. So far this line of thinking assumes that the entire public-school system of the United States can be treated as a coherent whole; the reality is that public education varies considerably between states and even between districts. Our society is admittedly diverse, so whatever core principles organize our educational priorities must cut across these differences. The search is on then for deep, commonly shared American values which could be transmitted between generations. Our society is neither a simple unity, nor are the values of a society fixed for all time. Societies change over time and so can their shared common understandings. This forces our answer to include a historical dimension. Whatever principles we see as determining the proper emphasis between the four stated purposes of education, must hold over time.

Core American Values

One approach to understanding what these core values are within the United States is to refer back to the literature and history it has passed on through its educational networks. For such an analysis it is fit to begin with two of the country's foundational documents, the *Declaration of Independence* and the *Constitution*. The *Declaration of Independence* sees the purpose of all governments to be the securing of certain inalienable rights including "life, liberty and the pursuit of happiness." The violation of these rights was stated as the cause behind America's need for independence and a new government, and hence can be seen as three of the core values our nation seeks to preserve and transmit. In this document, one sees personal goals triumph over social needs, but this was not the law of the land. The *Constitution* declares that the purpose of forming the United States was to "establish justice, insure domestic tranquility, provide for the common defense, promote the general welfare, and secure the blessings of liberty to ourselves and our posterity" (*Preamble, US Constitution).* Here the social imperative is clearly stated, with the first four reasons regarding the common weal, and only the last referring to a personal goal, namely liberty.

In his discussion of *Freedom & Culture,* John Dewey (1939) noted the "striking difference in temper" between the two documents and explains this in terms of the different purpose for which each was written. The *Declaration of Independence* was intended to rally individuals to a common cause; the United States did not yet exist. Seeking to overthrow the existing social order, the authors could only call upon shared individual goals, namely the common desire to escape the "tyranny" of the crown. The *Constitution* was written to provide the social institutions needed to create a common bond among the colonies and their inhabitants. Since the aim was to create, or recreate, the structure of government, it is unsurprising that the social needs came first, and the personal aims last. Governments exist to regulate social interactions, just as education generally, and schools specifically, exist to teach new members how to participate in those social interactions. While social needs, the good of the group, triumphed over individual needs, the latter could never be entirely ignored. It was the trampling of individual goals that led to the revolution, and this lesson has not been forgotten. Schools in the United States have therefore prioritized social aims over those of the personal, but never completely ignored the important role individuals. Much rhetoric has been spent on defining this relationship, which will be explored further below.

Social Control in Colonial America

The need for social control through education naturally preceded the *Constitution* and the forming of the new nation. Bailyn (1960) discussed the transformation of formal education that occurred as English settlers attempted to transplant their civilization to North America. In England, “The greater part of the mechanism by which English culture transferred itself across the generations”, the bulk of education in other words, was “accounted for” by “family, community, and church” (Ibid., p. 18-19). Thus, formal schooling focused on literacy, which as Bailyn argues, served largely a vocational purpose. In the colonies however, formal education or schooling needed to take on “cultural burdens they had not borne before", (Ibid., p. 21). This was because as “the once elaborate interpenetration of family and community dissolved", individual members of society “acquired an insulation of consciousness” (Ibid., 25). If members of a community no longer felt automatically compelled to participate in community, then they must be taught to do so. The succession laws of 1647, in Massachusetts and Connecticut, which required towns to set up schools, “flowed from the fear of the imminent loss of cultural standards” (Ibid., 27). As Bailyn so eloquently expressed it, “the maimed functions of the family” were “deliberately transferred” to institutions of formal instruction, and schools “expanded their purpose beyond pragmatic vocationalism toward vaguer but more basic cultural goals” (Ibid., p. 27). Here one clearly sees how the fundamental purpose of education, denied its function through informal agencies, broke into the realm of America’s schools. While the basic function had been taken by family, community, and church in England, allowing schools to focus on more vocationally oriented tasks; in America the challenges of transplantation required schools to take over much of social purposes of education.

Social cohesion in the New Republic

As the colonists fought for their independence from England, and began to organize a new government, the common values of the new nation needed to be inculcated into its youth. Kaestle (1983) has written about the role of schooling in the new republic. Social upheavals like the Whiskey Rebellion and Shay's Rebellion in the new republic underscored the need for maintaining order, with education seen as playing a key role in bolstering social stability. It was in order to "foster the intelligence required of republican citizens" that "eloquent political leaders looked to education", especially to "schools organized and financed by the states" (Ibid., p. 5). What "all republican educational theorists" agreed upon was the need to teach "the heavy responsibilities of citizenship" and provide the required "moral training for the survival of republican institutions" (Ibid., p. 8). The real contribution of this early period, as Kaestle points out, was not in providing "legislative precedents" but in revealing "what kind of schooling ordinary people sought" (Ibid., p. 12). From the early republic there emerges then an image of America's schools as social institutions serving the needs of the nation as bastions of republican virtues, at least in the rural countryside.

In urban centers, education took an earlier turn towards social control, at least regarding education for the masses. Popular education was seen much more favorably in the American cities, compared with England, because "Unlike English Tory opponents of mass education, conservative Americans generally believed in schooling for social stability. They feared ignorance, not instruction" (Kaestle, p. 35). What "the middling and upper classes" feared was primarily "immigrant vice, infidelity, and crime;" since the purpose of "charity" schooling was social stability, "little pretense" was given "to providing equality of opportunity or intellectual enlightenment" (Ibid., p. 36). While these were charity schools, designed for the masses of the poor, they also "laid the basis for the free school systems of mid-nineteenth century American cities" (Ibid., p. 37). The wealthiest families "hired private tutors" which allowed their children to obtain an education that focused more on personal and academic goals; while "those in the middling ranks" attended day schools which focused more on vocational aims (Ibid., p. 51). The needs of the new, yet growing nation, required the formation of strong norms of behavior and citizenship, thrusting Goodlad's other purposes of schooling to the bottom of the heap for the majority of students.

The common schools which followed charity schools retained a strong emphasis on moral education. Common schools, fought for by such "crusaders" as Horace Mann and Henry Barnard, were "dedicated to moral education and good citizenship" (Kaestle., p. 75). These common schools functioned to inculcate the dominant Protestant Christian views of America's bourgeoisie. "They trained children to be good citizens, the developed moral character and work habits" and "drew people into a common culture based on native Protestant ideology" (Ibid., 102). While these schools did "spread literacy" and offer "opportunities for individual advancement" those were consequences of schools fulfilling a deeper purpose in perpetuating social norms and structure. Individual goals did factor into play. As Cremin (1961, p. 11) recognized, American society saw itself as a free society, and "a free society concerns itself with individuals, not masses". Mann's solution was that "only in the arduous process of training children to self-discipline" did the common school fulfill "its commitment to freedom" (Ibid., p. 11). Freedom here meant self-discipline. For students to achieve their personal goals, they needed to learn to serve society first. By learning to restrain themselves, students would be better able to apply their knowledge, work their trades or professions, and thus realize their personal aims by fulfilling their social roles.

The American High School

William Reese (1995) studied the rise of American high schools from the 1820s to the 1880s. In summarizing his research on the *Origins of the American High School,* Reese found schools, “deeply embedded in political struggles that frequently strengthened the power of the white middle and upper classes at the expense of the less fortunate” (Ibid., p. xvi). In other words, the social purpose of school, still that of control, continued to predominate as high schools grew in number, overtaking academies and private schools as the most widespread form of secondary education. As the country continued to grow in population, urbanization, and industrialism, society itself was changing. It was “no simple matter", Reese wrote, “to identify core republican values and then adapt them to a rapidly changing society” (Ibid., p. 55). How did schools, especially high schools, accommodate these changes? Social leaders agreed upon the desirability of schools which “promised order, predictability, and discipline” (Ibid., p. 55). Teaching one’s place in the social order, and the individual moral character needed to remain there, was the central purpose of the rapidly rising number of American high schools during the antebellum period.

But what of content? Where did either academic preparation or vocational purposes enter 19th century schooling? While educators repeatedly emphasized from the 1820s to the 1880s that, “public high schools would promote republican values, reward talent, and thus secure social order”, content was considered a means to an end (Ibid., p. 80). What many agreed upon what the desirability of a practical education. “In an age of expansive economic growth, many educators--especially those accused of fostering knowledge for its own sake--emphasized the material advantages of higher learning" (Ibid., p. 96). The notion of a practical education, or useful knowledge, becomes key to understanding how the other three purposes of education (academic, vocational, and personal) were prioritized. What middle class families wanted, and it was their children who filled the high schools, were schools which taught "respectable social values and marketable skills" (Ibid., 101). Students and parents were mostly interested in "the cash value of learning" compared with educators who were generally "opposed narrowly conceived vocational courses" (Ibid., 100). The emphasis was neither on academics, as in a joy of pure learning, nor on vocationalism in regard to preparation for specific jobs. It is an "erroneous impression" that educators elevated the academic over the vocational, for the truth was that "few Americans valued learning for its intrinsic worth" (Ibid., 101). While there was much discussion about the benefits of a well-trained mind, "Mental discipline or the love of learning was never an end in itself" (Ibid., 102). Instead it was valued for its usefulness in all walks of adult life; "sound academics" in America's high schools were justified because they "produced practical results" (Ibid., 101). Schools were not yet ready to offer truly vocational education, although this would come later. Instead, the emphasis in American high schools from the antebellum through the postbellum periods was on useful learning, regardless of what employment students later took up.

The emphasis on utility of learning, of developing a disciplined mind and well-honed mental skill sets continues to be seen in the *Report of the Committee of Ten on Secondary School Studies* (NEA, 1893). A number of the conferences, in their individual reports, addressed the aims of education in their subject area, defending them based on their practical contributions. History was defended as "being better adapted than any other studies to promote the invaluable mental power which we call the judgement" (Ibid., p. 168). The proponents of history fought for its place in the secondary curriculum by favorably comparing it with subjects well accepted as practical. Indeed, the conference members declared, "The principal end of all education is training. In this respect history has a value different from, but in no way inferior to, that of language, mathematics, and science" (Ibid., p. 168). They went so far as to claim that history was in some ways more practical than science, "for the examples in a geological or mineralogical museum fill many shelves, while in history they may be brought within the covers of a few books" (Ibid., p. 169). Other conferences, including Latin, the modern languages, geography, used their contributions to mental discipline to justify their place in the curriculum.

Confusion in the 20th Century

As the new century dawned, and population growth, urbanization, and further industrialization continued to reshape America educational priorities became more confused. Recall, the central thesis that the purpose of education is to perpetuate a society; the more challenges a society faces in terms of changes to its make-up, the more the educational system is challenged to adapt itself to help. The confusion in education can be seen even in the increased attention the period from 1880 to the mid-twentieth century has received from historians of education. This period, centering around the work of the progressives, has spawned a plethora of books. This makes the historiography of education in the period much more confused as well, although certain salient points shine through several excellent secondary sources available for this period (Cremin, 1961; Krug, 1969; Tyack, 1974; Kliebard, 1995). The concept of mental discipline fell out of favor as the new century dawned, replaced with pedagogies based either on child-centered psychology or social efficiency. As schools grew in size, vocational education enjoyed a period of greater popularly after 1900. The emphasis on what was more practical, what benefited the student in finding their place in society continued. A last document, the *Cardinal Principles of Secondary Education* (NEA 1918) will summarize the key arguments being made.

The *Cardinal Principles* published by the NEA in 1918 stated that, "Education in a democracy, both within and without the school, should develop in each individual the knowledge, interests, ideals, habits, and powers whereby he will find his place and use that place to shape both himself and society toward ever nobler ends" (Ibid., p. 9). In other words, the personal purpose of education is attained by pursuing the social purpose. Given the above statement on fundamental function of education, the commission settled on a list of seven "main objectives of education", which were: health, command of fundamental processes, worthy home-membership, vocation, citizenship, worthy use of leisure, and ethical character (Ibid., p. 11). Here one finds the academic (the fundamental processes) and vocational purposes of schooling being pursued in the context of contributing to the common good. The "comprehensive school" was best suited to deliver such an education, as it was "the prototype of a democracy" wherein groups were "federated into a larger whole through the recognition of common interests and ideals" (Ibid., p. 26). This was achieved through group activities training students in cooperation, and through learning loyalty to the school, which prepared students for loyalty to the country.

The statements on the purpose(s) of education made in *Cardinal Principles of Secondary Education* illustrate how schooling in America has prioritized the social function over the academic, vocational and personal. This has been the case since colonial times when as Bailyn argued American schools needed to take on new responsibilities they had not known in England. Lacking the deeply entrenched social cohesion of many societies, America has needed to rely on formal education, or schooling, to shape its citizens into useful and productive members of society. What had elsewhere been achieved through more informal means needed to be addressed in America's classrooms. Unable to prioritize academic, vocational, or personal goals, schools in the United States were designed to meld its young people into a coherent society. This process began as soon as the thirteen colonies declared their freedom from England. The pressing need to inculcate young people in the shared values of land (based on those of the upper and middle classes) drove the development of rural and urban schools alike. As the population grew, common schools and later high schools emerged, but retained the common goal of preparing useful citizens for participation as adults in a democratic society.

Section Summary

This section has sought to show how throughout its history American schools have served a conservative function to maintain society. Indeed, schools are the formal means by which society inculcates its youngest members in its norms; it seeks to shape them into productive adults. Despite these efforts on the part of schools, striving to produce new members of society able to carry on the work of the previous generations, society itself continues to evolve in order to meet both internal and external pressures. Society then wrought change within the schools, causing them to play catch up. That this is the case will be seen in the discussion of changes to how physical science was taught in American schools. Physics emerged from Natural Philosophy as a consequence of the changing landscape of industry, technology and scientific progress. As society demanded more workers with a fundamental grasp of the technology and scientific principles underlying modern industry, schools sought to shift to a pedagogical approach which favored more hands-on investigations by students within their physical science classrooms. In the next section I discuss aspects of my methodology and how I believe a history is built.

Methodology: How Do I Build A History?

This section discusses the significance of historical facts, and how it is the interpretation of documents and the meaning attached to them that generates the narratives of history. It is my belief that all history is ultimately narrative and that the stories told are used to share the author's conception of how our reality unfurled. I begin with a personal anecdote of a youthful experience in which the role of the observer became clear to me. History takes place within the individual mind; within these individual experiences of memory or interpretation memes can be found and passed along, creating a social reality around a topic. Yet, ultimately history remains an individualized story, which is why no one tells the same tale and we each have our own conception of the past. Following a discussion of epistemology, interpretation and the nature of historical truth, this section turns to the nature of reforms in education, and finally to the use of textbooks as a historical source.

I recall visiting a museum in Vienna. Among the many artifacts on display was the uniform Archduke Ferdinand wore when assassinated. What lay before me was simply an old garb with round holes lying beneath a glass pane. Yet in my mind's eye, I recognized the relic of an event which ignited the powder keg of the Balkans, setting the Great War in motion. My ability to see the events tied to the tattered uniform was due to my undergraduate course in modern European history. Without some understanding of the events which preceded them and the motives and aspirations of those who are involved in them, current events would be entirely unfathomable. The more one knows of what came before, of the historic context of an event, place, or peoples the larger one's consciousness and awareness of what lies before one's eyes. This is the power of history; it creates meaning! The past is constantly exerting an influence upon us, both large and small. Not all events are not equally momentous, but we are daily responding to the consequences of earlier events, both in our personal, immediate pasts (the choices we made during preceding days, weeks, and years) as well as in the shared global past (the cumulative sum of human history).

The Work of a Historian

Regarding our ability to discover the truth in history, my own epistemological stance is that while the past was real, for we can discover historical facts, our knowledge of those facts, and therefore any stories we can tell about them, will always remain imperfect; in this regard I might be considered a post-positivist. But, there is more to history than discovering true facts; these facts must be sorted and assembled into a working model. The past is a jumble of facts, and the task of a historian is as much to bring order to this disorder as it is to uncover details about the past. Adding in irrelevant details only muddles the explanation. The incredible complexity of the past resists reproduction and requires thoughtful reconstruction.

J. L. Gaddis (2002) has described the work of historians as abstractionists, artists who must apply judgment in what to leave out of their researches. He argues it is impossible to bring to life every aspect and every fact about any period of history. The utility of a model depends on its ability to present the necessary information without including extraneous data which detracts from its purpose. If a historian were somehow able to include everything which happened in the past, the history would be as confused as the past had actually been. Indeed, it would be the past all over again. There would be no perspective, no lessons learned, no direction or purpose to the replication of the past.

To create useful models of the past, historians need to select important facts and fit them to appropriate scales of time and space (Gaddis, 2002). This is something akin to the Heisenberg uncertainty principle, which Gaddis also cites. In the study of atoms, one can know more either about their location, or about their trajectory, but never perfectly know both. In historical terms, the more we try to resolve a certain image of past events, the more we lose the context within which the event took place. The more one focuses on the known facts of a period, the less one focuses on the meaning of those facts. One must choose then either a broad general survey without great resolution, or a rich, narrow slice of the past. I have chosen the latter, to view a specific aspect of the past from a certain vantage point with a given angle; this determines much of my relationship with the past and forms another aspect of my positionality.

History is often defended for its function in helping us understand the present by way of understanding how that present arose. Hegel (1840/2009) held that by studying history one could find pure reason revealed. More recent historians however question the extent to which we can perfectly understand the past, tending towards a more post-positivist perspective. “The best you can do...is represent reality: to smooth over the details, to look for larger patterns, to consider how you could use what you see for your own purposes” (Gaddis, 2002, p. 7). Gaddis continues, “Studying the past is no sure guide to predicting the future. What it does do, is it prepares you for the future by expanding [your] experience” (Ibid, p. 11). A similar argument has been made by DeBoer (1991, p. xii) about the history of science education; a more informed knowledge of the historical record, “Makes our decisions about curriculum and instructional strategies more intelligent and our evaluation of those strategies more cautious.” The purpose of history then includes a sense-making function, and this is one criterion by which any given history must be judged: does it help explain our world?

Epistemology, Interpretation & Historical Truth

As Gaddis (2002) explains, writing history requires selecting relevant facts in the historical record and making sense of these facts by looking for patterns and causal relationships while working to create a model of the past. Hegel called this fusion of fact and interpretation "reflective history" (Hegel, 1840/2009). The importance of historical interpretation seems inescapable. Gadamer (1960) argued that it is the very act of interpretation which gives meaning to the dead facts of the past. According to the hermeneutical tradition, to which Gadamer belonged, we cannot understand the past on its own; we can only really understand the importance of past events to ourselves, to our day and time, and really this is all that matters. This raises the specter of absolute relativism leading to a post-modern quandary: are all historical inquiries of equal worth? If history is a matter of interpretation, not fact, then are not all interpretations equally valid? Who is to judge?

Fortunately, criteria do exist for finding a path through the jungle of historical opinion, and there are means of judging the quality of historical research. The quality of historical scholarship rests on the consilience of the researcher's claims with the relevant facts, on the author's ability to reveal new insights into a significant portion of the past, and the ultimate coherence of the analysis. Hastily constructed, loosely argued essays which rely on shoddy sources (or none at all or fails to cite them) is deemed inferior to scholarship presenting a tightly knit account of the past, revealing its key features, bringing key sources to the fore. There is a difference between assessing the quality of the work produced from a given perspective and judging the individual who holds it.

Rury (2002) like Lagemann (2005) insists good history must be both an art and a science but goes further in explaining the role of each. The science lies in the historian's ability to handle the facts of the matter. Not only must, "the story the historian constructs...conform to the historical evidence," it must also be "tested" against the best available information (Rury, 2002, p. 19). While historians must "identify what in fact occurred in the past," and to "set the record straight," they must also "make judgments" about what is "truly significant" in the "great mass of surviving materials" (Ibid., p. 19). Here begins the historian's art. Great historians not only have a command of accurate facts, they are able to paint impressive pictures revealing the motives and mechanics by which the worlds in which people lived operated. "The historian aims to reconstruct history as it occurred, while offering explanations that help one understand the past in terms familiar today" (Ibid., p. 20). Thus, the historian serves an interpretivist function, needing to reformulate historical facts so they speak to us in the present.

The richness of the "facts" mined from the historical record provide the base value of a historical work, yet it is the way those facts are fitted together into a coherent mosaic which provide a work's artistic value. High quality history includes a clear, coherent interpretation of historical facts, probing into the past with a light so bright it reflects and refracts onto other questions that those originally proposed. The reader is thus provided with a robust understanding of the past, which proves useful in further inquiry. First the facts must fit together, else the history is of poor quality, but secondly the resulting mosaic must somehow make sense, revealing something of meaning or importance, otherwise the history is irrelevant. Relevance comes less from explicit statements by the author (such as, "...and this is how the past explains the present" or, "...and that is why this is important"). Rather it comes from resonance with the reader. When a reader feels their minds transformed, when they see new truth in old knowledge, when their conception of the past is sharpened, or they leave a work with new meaning in their lives, then a history has transcended the mundane and acquired real value.

The Nature of Reforms

One of the first methodological issues I struggled with, and one which undergirds my entire approach to this topic, concerned the relationship between what is written and what has actually transpired. In the context of my study, this means the relationship between the writings of educational leaders and experts, and the extent to which these impacted lives in the classroom. As a classroom teacher, I know few reforms are followed to the letter; most teachers continue to teach as they are accustomed to. The refrain, "This too shall pass," is commonly grumbled within school halls as new initiatives rain down from above. And yet I remain convinced that not all efforts at reform are mere whistling in the wind. There must be a connection of some kind between what reformers recommended and what was actually happens in America's classrooms. If I aim to write a dissertation on how historical practices of laboratory activities related to larger reform efforts, then I this issue over the connection (or disconnection) between historical sources and reality becomes one I must resolve.

At least part of an answer is found in the writing of H. M. Kliebard (1995). His *The Struggle for the American Curriculum: 1893-1958* has been one of the most influential works on the history of education I have read. This text not only introduced me to the history of American education, it began to shape (in my mind) the relationship between reformist writings and the events of history. Kliebard explains in his introduction that he treated written documents, "not as influencing the course of events, but as artifacts of a period from which one might be able to reconstruct what was actually happening in the teaching of school subjects" (Ibid., p. xiv). I left this with a more incisive understanding of how to interpret the written sources. First, it was wisest to discard the notion that "major leaders" influenced events in the classroom through their writings. Second, such writings are best interpreted as products of their time, *influenced by* rather than *influencing* the realities of the period.

The utility of documents, whether written by "major leaders" or minor figures, lies in their ability to grant insight into the minds of those who wrote them, to understand what educational realities the authors were responding to and what they sought to achieve. Such ideas Kliebard continued, "must be seen against the backdrop of the hard realities, not only of school practice and the bureaucratic structure of schooling in this country, but the political and social conditions of the time" (Ibid., p. xv). This approach to the primary sources informs the work ahead. To provide an example, the *Cardinal Principles of Secondary Education* (1918) says more about the state of affairs in 1918 when it was published, than about what began to happen in 1919. The achievements, or failures, of educational leaders is better assessed by examining the historical document that followed, such as the Harvard Report (1945) *General Education in a Free Society.* The *Cardinal Principles*, likewise, are useful in assessing the successes and failures of the earlier work by the Committee of Ten (1893). The importance of these reports lies not in their ability to dictate what was to come, but rather in revealing what the authors saw as the most relevant needs of their own time and how they hoped to address it.

This work, in the spirit of synthetic history, seeks to move beyond polarized positions. Moving between the camps of consensus historians and revisionists, this dissertation attempts to understand the influence of social, cultural and intellectual influences on school reforms, while acknowledging the sometimes-self-serving nature of humanity. Schools did not serve all students equally, and even the most altruistic reformer had personal reasons for their agenda. Certainly, the individuals featured within this narrative were motivated by a combination of their personal beliefs (axiology), perception of the world around them (ontology), and sense of the truth (epistemology). This only makes them human, it does not warrant the wholesale rejection of their views for being "dead, white men." Like us all, they responded to the world around them in a combination of self-interest and altruism, working to bring reality closer to their inner ideals. Rather than negate their value as historical sources, such humanity necessitates situating them within their time and place.

Strategic considerations guided me in choosing a mere three decades and one branch of science (physics) to focus on. Only as one's lenses are trained more tightly, do essential details come into view. Still, as with microscope work, switching between low, medium and high-power objectives is needed to see how the pieces fit into the whole. One must rotate through these various powers of magnification to get a full sense of the specimen lying on the stage below. Scrutinizing at high power the recommendations textbook authors made to teachers, especially regarding laboratory practices, I hope to understand such practices within the larger context of educational reform efforts (medium power) and larger social trends (low power). With any given eyepiece, high power magnifies details, but lower power grants a larger field of view. Such a larger field of view is helpful in situating cells within the structures they function in.

During the five-year journey of writing this dissertation, my methods have varied with the season. Some of my methods I have borrowed from grounded theory (Marshall & Rossman, 2011). Early on as I read through relevant sources I tagged what seemed relevant to my research questions. Occasionally I would then revisit these tags and label them with a code that helps me to help identify their significance (open coding). As I continued to read, and reread, I began to code axially (across my notes), comparing sources and how they might intersect. During this process, I looked for patterns and create categories which my codes may sort into (such as: "social background," "structure of schools," or "lab or lecture"). I sought themes which might provide more meaningful arrangements of the data and thus leading to more coherent explanations of the historical phenomenon. During this process of researching and organizing my research, I tried to triangulate the emerging patterns by comparing the various primary sources with each other (and against the conclusions of historians in secondary sources). These analyses produced initial findings which could then be combined and revised from which a final, coherent narrative and analysis might be built. However, I gave up this method after some time, finding it too restrictive and mechanical. I then sought for a time to apply the cross-cutting concepts of the *Next Generation Science Standards* as a sense-making tool (NGSS, 2013). I finally found the best way forward was to just begin assembling what I had. I would take a source and write about its most significant features. One summer I began using the process of storyboarding to assist in arranging the many pieces of the puzzle and help me to hone in on what really seemed most important. From that the current structure of this dissertation. In the end, it became what I first sought to avoid, following the chapter divisions of what is now a traditional dissertation in education.

Textbooks as historical sources

It has become methodologically fashionable of late in the history of education to examine textbooks as a form of primary sources (Bertomeu-Sanchez et al., 2006; Turner, 2011; Kremer, 2011; Meltzer & Otero, 2015) as a means of moving beyond the standard accounts given previously. As they, “Offer hints about this intricate space [located at the intersection between scientific knowledge and pedagogical views] because they are located in a crucial place among the multiple and diverse factors and actors that shape educational practices” (Bertomeu-Sanchez et al., 2006, p. 659), textbooks can prove valuable historical sources. Textbooks may shed light on an author's “particular backgrounds and goals” as well as an audience’s “aims, expectations and reading practices” (Ibid., p. 659). Other more traditional sources will be drawn upon in addition to textbooks, including the standard fare of NEA reports, writings of certain leading reformers and articles published in teaching journals during the period.

Section Summary

In this section we have explored my conception of how history is best understood. It is simultaneously a figment of the individual imagination and also a powerful narrative which can be shared. As a lens, it filters the multitude of historical evidence and presents a refracted portrait of what has come before. After discussing the work of the historian and explaining my conception of truth, I shared how efforts at reforms are more informative of their antecedents generally than as a prime mover of what is to follow. Efforts at reform have, however, changed and colored the ideals which guide the work of teachers. I cannot testify to how many students actually began applying the inductive method as Wead (1884) would have desired but can state that his report served to substantiate the work of textbook authors seeking to promote a laboratory-based physics course. These textbooks showed teachers what the newly emerging ideal was, whether or not teachers were able to attain that ideal. The next section brings this chapter to a conclusion.

Chapter Summary

This chapter has focused on my methodological approach to a historical dissertation in general and the topic of *physics'* emergence from *natural philosophy* specifically. The first section examined my positionality and how knowing it may help interpret my research. The second section took my understanding of schooling in America as an example and an interpretive frame. If you believe that schools *did* serve the interests of the individual over that of society, then we would likely come to different conclusions even if we examined the same sources. In the third section of the chapter we looked closer at how I conceptualize the process and function of historians.

No two historians, thankfully, tell the same tale. We each frame our work differently, shine a different light from a different angle, and so reveal different features which we then interpret according to our own positionality. Another historian might approach the same period and topic with a different set of questions, leading them to select different sources and interpreting these according to a different set of values, interests and background knowledge. Our understanding of history is thus a deeply personal matter.

From such a perspective, I could be labeled an interpretivist working with an inductivist methodology. My work is inductivist in that my answers emerge as the research progresses (Saldana, 2015); I did not have a hard research agenda or thesis to test from the outset, but rather allowed it to coalesce as I worked through the literature. I ventured out on this project accepting that I did not know what I might find as I read through the primary sources or what conclusions I might reach. Even after defending my initial proposal, by period of concentration shifted by two decades. I may also be considered an interpretivist (Ibid.), as the real work of the historian is in making sense of the sources (the factual material) and building a narrative from those raw ingredients. The truth of what happened in the past and what it meant is emergent and dependent on the lived experience of the scholar.

The next chapter contains an examination of the primary documents. From these documents I constructed a narrative as to the emergence of a new instructional tradition in American science education. This emergence can be taken as a case-study of how new ideals emerge in response to changing social needs. As argued previously, education is inherently conservative, working to maintain the essential norms and traits of a society. However, as a society transforms, so too does its expectations of its educative system. Schools react to the demands of society, and the emergence of the laboratory method in high school physical science is an example of one transformation. The expectations in and of a *physics* class truly were different than in a class on *natural philosophy*.

CHAPTER 4. FINDINGS -- NATURAL PHILOSOPHY & PHYSICS

This chapter presents the narrative of change as physics emerged and displaced natural philosophy as the ideal course of instruction for physical science in late 19th century America. It digs deeper into the primary literature to examine instructions given to teachers in published textbooks of the period. The chapter begins with an examination of *natural philosophy* which the was the dominant instructional tradition at least until the 1880s. The term *tradition* is used to connote a certain way in which a subject, such as physical science, is taught. The second section of the chapter examines a few textbooks which advocated a different approach, but of the three discussed only one was aimed at the secondary level. In the third section the chapter examines the reports and the textbooks which marked the emergence of physics as a new instructional ideal during the early 1880s. The term *instructional ideal* is used because this dissertation focuses on the discussion around what instruction *should* look like. The fourth section covers the second half of the decade in which the new approach gained further support, both in the professional literature and by its adoption at Harvard as part of their entrance examination. The last section tells the story of the new tradition coming into maturity as advocates sought a practical balance between laboratory work and other elements of instruction such as lecture, reading, and discussion.

As a curricular tradition, *Natural Philosophy* emphasized science as a literary study of known phenomena. Students were expected to learn *about* science: studying texts and listening to lectures before being examined by recitation. Science was seen not as an activity, but as a mountain of knowledge to be mined for its utilitarian value. Students were therefore rarely encouraged investigate nature themselves during such classes. The tradition of high school

Physics which emerged in America during the 1880s sought to bring the ideals of the *Scientific Revolution* into the classroom. These ideals had been developed centuries earlier by the likes of Galileo Galilei (1564-1642), Francis Bacon (1561-1626), and Rene Descartes (1597-1650). Such scientific ideals included skepticism about inherited wisdom and a preference for direct, personal investigation. While accepted by serious practitioners of science, these ideals did not yet extend to the science classroom and the instruction of students in the middle of the 19th century. Towards the end of the century, these ideals did emerge in the classroom under the new course title *Physics,* but before then *Natural Philosophy* held sway.

The Tradition of Natural Philosophy (1833-1879)

This section seeks to elucidate the main traits of the *natural philosophy* tradition of teaching physical science in the secondary schools of 19th century America. For most of the century natural philosophy was the dominate tradition by which students in school learned about the physical world around them, what its parts were, and how it worked. This tradition held sway until the 1880s, when a new, more experimental tradition emerged, centered around the student laboratory and bearing the title *physics*. The section proceeds by examining in turn a selection of the textbooks from the period accessed from the excellent bibliography put together by Meltzer and Otero (n.d.). This selection of texts demonstrates the heavy emphasis on rote memorization and recitation common to this tradition, with experiments conducted by instructors as a means of motivating students and clarifying concepts found in the textbook. In this tradition, students were learning about the world and gathering up a store of useful knowledge rather than learning to investigate nature first hand.

Prior to the rise of the laboratory method and physics in the 1880s, physical science was largely taught by recitation from a textbook. This heavy emphasis on textbooks, rote learning, and recitation mark natural philosophy as an instructional tradition distinct from and preceded the tradition of *physics* which emerged in the 1880s. Evidence for this comes from several sources. The primary source of evidence are the textbooks themselves which were published in the period before 1880 (Olmstead, 1833; Parker, 1844; Quackenbos, 1860; Norton, 1870; Peck, 1871; Steele, 1871). Articles published by persons interested or invested in the outcomes of school science corroborate what is found in the textbooks (Trowbridge, 1879.) Reports by leading authorities drew attention to the problems inherent in the tradition (Clarke, 1880; AAAS, 1882; Wead, 1884). Textbooks after 1880 echo the concerns found in the reports and used the inclusion of laboratory work to distinguish themselves (Gage, 1881; Avery, 1884; Trowbridge, 1884). This interpretation of events is further supported by recent work of other historians (DeBoer, 1991; Turner, 2011; Rudolph & Meshoulam, 2014; Meltzer & Otero, 2015).

American textbooks on physical science published for secondary school use before 1880 revealed a design for learning based on acquisition of facts, book-study and recitation without the benefit of laboratory work (Olmstead, 1833; Parker, 1844; Quackenbos, 1860; Norton, 1870; Peck, 1871; Steele, 1871). These features identify a tradition of instruction known as *natural philosophy*. Rather than seeing science as a way of learning, as a method or process, natural philosophy saw science as a body of knowledge to be acquired. The cheapest and most efficient means of doing so was to have students read a textbook, commit the knowledge to memory, the mastery of which was demonstrated through recitations. The notion of students investigating nature by conducting laboratory work of their own, so central to current ideas of how science ought to be taught, was remarkably absent. The reasons for this absence will be discussed further, but it appears to have been a consequence of expediency (cost, time, and lack of qualified teachers) together with a lack of imperative (there was no great pressure from outside the schools to teach experimental physics). When experiments were included in these earlier textbooks, they were meant as teacher demonstrations to be performed in front of the students. As these experiments served to illustrate points discussed in the book, several authors suggested they could conveniently be replaced by illustrations found in the books themselves.

"Condensed and Intelligible" (Olmsted, 1833)

The American tradition of natural philosophy in schools and academies can be traced back at least to Denison Olmsted, professor of Mathematics and Natural Philosophy at Yale. In his *Compendium of Natural Philosophy (1833).* The subtitle identifies its adaptation for both "the general reader" and "schools and academies." Olmsted felt it was the "truths" of natural philosophy and their application that was of greatest importance for "every well-informed reader" and not "the reasoning by which they were established" (Ibid., p. iii). For this reason, his stated purpose in his text was to present the "practical results of Natural Philosophy (without the demonstrations) in as condensed and intelligible a form as possible" (Ibid., p. iii). According to this way of thinking it was a knowledge of the results and application of science which benefited the general reader, and not a knowledge of how such "useful discoveries" were made. Such thinking was perhaps practical, but certainly against the spirit of inquiry praised by the scientific revolution and its distrust of unexamined knowledge.

In his instructions to teachers, Olmsted exhorted teachers to make "a free use of the Analysis" as it provided "a clue to all the leading truths contained in the text" (Ibid., p. v), for the chief goal of instruction was to promote rote learning and recall. If these headings were "frequently reiterated" such as at the "commencement or at the close of each class" then the learner might gain the "entire possession of the contents of the book." The best assessment of successful study was if the learner could give "a correct and full account of each of these heads" during a recitation, ensuring that "the leading truths and practical applications of philosophy" would be "indelibly engraven on the memory of the learner" (Ibid., p. v). At this stage it was the dissemination of discoveries that mattered; America's educational leaders were not yet seeking to instill an understanding of how science worked, but rather to share the fruits of such labor.

"But Little Originality" (Parker 1844)

In 1844 Richard Green Parker, Principal of the Johnson Grammar School in Boston, decided to issue his own science textbook entitled *The Boston School Compendium of Natural and Experimental Philosophy* in its twelfth edition. This to complement his previous works on English instruction dealing in turn with Composition, Grammar and Rhetorical Reading. At this early date, there was no need for a textbook author to have specialized in the sciences in order to publish about it. Textbooks at this time borrowed freely from other older texts, for as Parker admits, such work allowed for "but little originality" (Parker, 1844, p. vi). At that time, in the middle of the 19th century, science was seen by many as a body of facts amalgamated from previous scholars. "The whole circle of the sciences consists of principles deduced from the discoveries of different individuals, in different ages, thrown into common stock" with the author of an elementary treatise being judged mainly on "the judiciousness of its selection" (Ibid., p. vi). Few who examined textbooks for classroom use seemed to object to such liberal borrowing. The fact that his *Compendium* reached twelve editions is sufficient testimony to its popularity.

What schools were looking for was a text easy in its use for book study and recitation. Book study required concise explanations and clear definitions; recitation required passages easily identified for examination. Parker promised to deliver on both fronts as his book was "peculiarly adapted" to "the convenience of study and of recitation" an effect achieved by placing the figures and diagrams both within the text and again at the back of the book, where they could be readily referenced for recitation (Parker, 1844, p. v). Questions for use in both independent study and recitation were included at the bottom of each page. The intent was again to build a command of the principle scientific knowledge of the times. To further enhance the clarity of material covered Parker used two sizes of font, a larger one to indicate the key principles and a smaller one to explain the significance of the principles. While the title suggests experimental work, the book in truth only contained "an engraving" of the apparatus housed at the Boston School with "a description" and "an account of the experiments which can be performed" (Ibid., p. iv). There was no expectation that most teachers, much less students, would conduct actual experiments in order to convey the spirit and method of investigation.

"With or without apparatus" Quackenbos (1860)

An author whose work illustrated well these features of the natural philosophy tradition is that of George Payn Quackenbos. In strong contrast to the textbooks appearing in the 1880s written by physics specialists like Alfred Gage (1881), Trowbridge (1884), and Horatio Chute (1889), Quackenbos was a generalist scholar. He was not only the author of one of the most popular physics textbooks prior to 1880 (Meltzer & Otero, 2015), but also authored textbooks on composition (both "First Lessons" and an "Advanced Course") and on history such as the "Illustrated School History of the United States (Quackenbos, 1862, p. 2). In his *A Natural*

Philosophy (1860), Quackenbos illustrated the traditions emphasis on logical progression of ideas, clear explanations, and the use of illustrations. As he writes,

> The author has sought to render a subject, abstruse in some of its connections, easy of comprehension, by treating it in a clear style, taking its principles on at a time in their natural order, and illustrating them fully with the facts of our daily lives (Quackenbos, 1860, p. 3).

In this Quackenbos described key features of what his text offers, namely a textbook which focused on readability and choice of illustrations, exemplifying the needs of teaching physical science as a book-study subject.

Upon further reading it becomes clear what is not present in the Quackenbos text: any emphasis on student laboratory work, independent investigations, or student developed projects. Quackenbos suggested that a "brief yet complete course" may be had by leaving out a study of the "apparatus and experiments" and restricting study to only the "leading principles" of the field. Since "the majority of schools have few facilities for experimental illustration," at that early stage of physics instruction, Quackenbos (1860, p. 4) felt that creating a text which could be used "with or without apparatus" was seen as a selling point worth mentioning. This was deemed so worthy of mention, the following claim was written just below the title, "Adapted to use with or without apparatus, and accompanied with full descriptions of experiments, practical exercised and numerous illustrations" (Ibid, p. 1). This brief description may give the false impression that Quackenbos is opening the door to having students conduct laboratory investigations. The reason that Quackenbos saw it as a selling point that his text could be used with or without physical apparati is because of their cost and frequent lack of availability. This is made clearer in the following passage.

> An important feature of this work is its adaptation to use with or without apparatus. The majority of schools have few facilities for experimental illustrations. The wants of these are here met by a free use of engravings, full descriptions of experiments, and explanations of their results (Ibid., p. 4)

Quackenbos makes it clear that it was not the desirability of greater experimentation that inspired the inclusion of experimental descriptions and the adaptability of his course; rather it was the desirability of excluding teacher conducted demonstrations. The results of experiments were given to allow students to learn them without having witnessed the experiment, much less conducted it. Indeed, Quackenbos felt by using pictures most schools could avoid purchasing equipment. Even very simple experiments, such as observing the path of a projectile, were depicted in an illustration rather than carried out by students (Figure 8). The current equivalent is showing students YouTube videos of experiments rather than having them use their own hands and collect their own measurements.

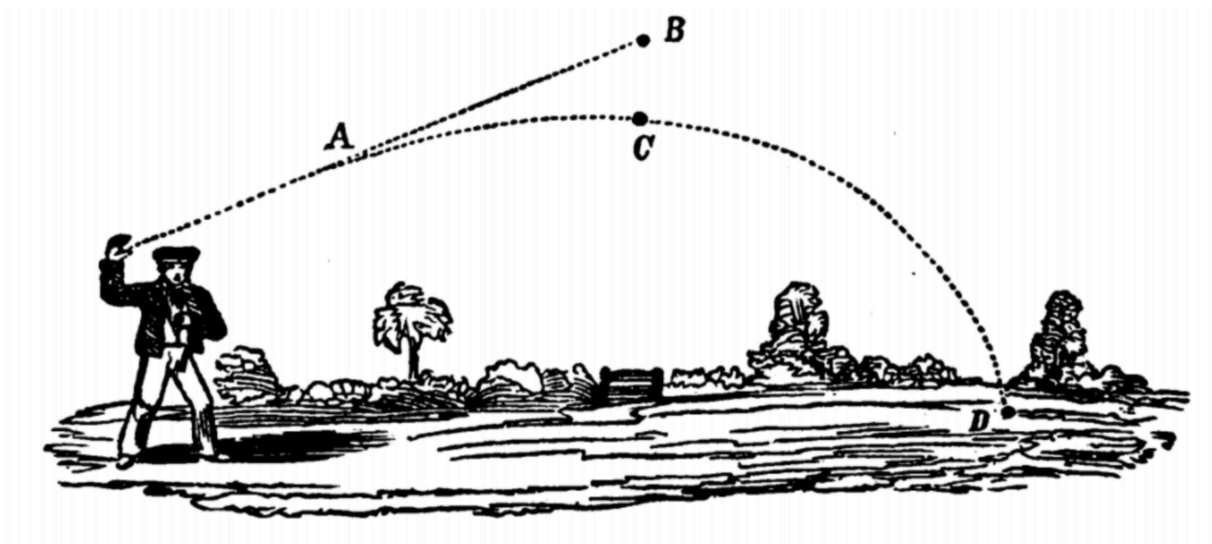

Figure 8. Person Throwing a Stone to Illustrate the Path of a Projectile (Quackenbos, 1860, p. 410).

In order to facilitate the use of his book as a purely cram-text or literary study of physics, Quackenbos as previous authors had used two type fonts purposefully. This was done to create two courses within one textbook, a short course for those schools with little time for physics, and an extended course for those seeking greater details and depth.

> Two styles of type are used in the text; a larger size for leading principles, a smaller size for descriptions of apparatus and experiments, explanatory illustrations, &c. By confining a class to the former when the saving of time is an object, a brief yet complete course may be taken. Questions at the bottom of each page will be found to facilitate the examiner's duty, and to afford the pupil a means of testing his preparation before reciting. (Quackenbos, 1860, p. 3)

The purpose was to facilitate the ease of examination and student preparation for such recitation. Leaving out all such discussions of experimentation would still lead to a "complete course" for in the tradition of natural philosophy more important than a deep and intuitive grasp of physical phenomena was the acquisition of fundamental facts and preparation for examination. Quackenbos considered such an abbreviation a benefit and a service for it met the needs of his market, the schools of the 1860s.

Quackenbos mentioned the inclusion of questions; these questions provide further evidence of the rote memorization of a wide collection of physical facts that the tradition of natural philosophy valued. Examining some of these questions shows they were largely low-level questions in terms of cognitive demand (See for example Costa's level of questioning). Here are some of the questions from the first chapter on *Matter and its forms,* "What is Matter? What are different kinds of matter called? Give examples." (Ibid., p. 7) or again, "Into how many classes are bodies divided? Name them. What is a Simple Body? What is a Compound body?" (Ibid., p. 8). Quackenbos claimed in his preface would prove useful in assessing students' learning, and as such they can be used to judge what sort of learning was expected of students. The questions show that the emphasis was not on the ability to puzzle out problems, or the ability to investigate nature by designing and conducting experiments which we associate today with physics classes. Such an approach did not yet make sense in a world where many teachers were asked to teach science with no prior college coursework in that area.

Quackenbos (1871) brought out a revised edition of his textbook a decade after his initial offering; in it he saw the need to update the accuracy of the content yet not the methods or approach indicating his confidence in his brand of natural philosophy.

> Recent discoveries in the different departments of Physics, and the general acceptance of new theories with respect to the kindred forces, Heat, Light, and

Electricity, having rendered necessary certain alterations in the text, the opportunity has been improved to revise the whole work (Ibid., p. 3).

It was the advances of science, not of pedagogy, which necessitated the revisions. Other textbooks of the period we will see reveal similar traits. The lack of change in pedagogical approach reveals the strength of natural philosophy tradition. Change seemed slow, or non-existent for most of the 19th century while the dominant tradition held sway, but change came rapidly in the 1880s, at least in terms of the instructional ideal. If one compares the remarks of Quackenbos (1860, 1871) with those of the Committee of Ten (NEA, 1893) thirty-one years later one begins to properly gauge how much the thinking around how to teach physical science had changed. How this change came about and what factors drove it will be discussed in the following sections of this chapter.

"A selection of facts" Norton (1870)

The Elements of Natural Philosophy published by Sidney A. Norton in 1870 revealed both familiar features and more novel ones. Norton again exemplified the tradition of science being a body of knowledge best learned through book-study, rather than a field unfolding through experimentation and best investigated in the laboratory.

> "In its preparation, the author has endeavored to keep constantly in mind that its value must depend on its availability as a text-book. Accordingly, he has made such a selection of the facts and principles embraced in the wide range of Natural Philosophy as, in his judgment, is best suited to the requirements of the pupil (Norton, 1870, p. iii/ 12).

Norton also shared another trait common to the natural philosophy tradition, that is the penchant for classifying knowledge. At the end of each chapter, a recapitulation was included which broke the content down into a simple outline for review. Electrical phenomenon for example could be divided into electricity which could be insulated "Statical" and that which is continually discharged as currents "Dynamical" (Ibid., p. 444). This was then followed by enumerating the types of "dynamical" electricity and followed by four applications.

What makes Norton somewhat distinctive is the inclusion of a series of quantitative problems in an appendix for students to solve. These problems were "not only to test the knowledge acquired by students, but also to lead him to think on the nature of the laws and principles required for their correct solution" (Ibid., iv). Looking at these included problems, one finds them not dissimilar to the sort of quantitative questions commonly found in AP Physics textbooks until recently. Students were expected to compare the speed a 3-ton battering ram needed to be swung in order to have the same impact as a cannon ball weighing only 30 pounds but travelling at 1,200 feet per second. Still teaching physics as a book-bound subject, in Norton's problems one sees the emergence of requiring students to *reason* or *figure out* how to apply knowledge to find solutions rather than merely memorizing facts. They were being asked to apply the principles of physics to calculate solutions to written scenarios. While not hands-on, such deductive reasoning was at least more involved than straightforward recall. This would become increasingly common as a distinct tradition of teaching physics developed.

"Classification of the Sciences" Peck (1871)

William G. Peck brought out his *Introductory Course in Natural Philosophy for the Use in Schools and Academies* in 1871, the same year Quackenbos revised his textbook. A loose translation of a famous French text by Ganot, the book serves as an example of continued European influence on how American students learned science. Among the texts produced in the 1860s and 70s, "those of M. Ganot stand preeminent" for their popularity not only in France, but also for being "extensively used in the preparation of the best works on Physics...issued from the American press" (Peck, 1871, p. v). Not only was the text of Ganot popular as a basis for American editions, but even the illustrations were reused by American authors writing distinct texts (such as Steele, 1871) making it a strong exemplar of what was valued in texts on natural philosophies.

In the text by Ganot/ Peck one finds further evidence of several traits common to texts of the natural philosophy tradition. For example, science is again seen as a body of knowledge which first needed to be classified and defined before it could be discussed and finally connected with the world of experience. The introduction opens with a "classification of the sciences" and the first sentence by defining science as, "A knowledge of the laws that govern the Universe" (Ibid., p. 9). No reference to experimental method is made. This is one of the most striking features of the tradition; it misses the sense of science as an activity in which truth is found through experimentation. The work of Ganot/ Peck ran counter to that very notion of learning physics through laboratory work. Rather than including illustrations to guide hands on investigation by students, illustrations were included in order to *replace* experimental demonstrations as in the Quackenbos text. The focus was on creating a curriculum of efficiency and expediency, exposing students to the ideas while avoiding what was seen as either unnecessary or undoable, namely laboratory work by students.

> It is profusely illustrated with beautifully executed engravings, admirably calculated to convey to the mind of the student a clear conception of the principles unfolded. Their completeness and accuracy are such as to enable the teacher to dispense with much of the apparatus usually employed in teaching the elements of Physical Science (Ibid., p. vi).

A science teacher today, serious about their craft, might be surprised and baffled at the expressed desire to eliminate the need for "much of the apparatus" but as with Quackenbos, this was most likely due to the cost of such equipment and its relative shortage in most schools. Official reports and textbooks in the 1880s bear out this hypothesis, for in building the case for student laboratory work, they argued that scientific laboratory equipment need not be expensive for student purposes. Indeed, several works of the 1880s made a point of disparaging the possession of a small collection of expensive equipment locked safely away from students' prying hands (Gage, 1881). However, one should not miss that these statements were intended to facilitate the teaching of natural philosophy, and a sign that demand for its inclusion in the secondary curriculum was increasing.

"The Recitation" Steele (1871)

J. Dorman Steele, Principal of the Elmira Free Academy, brought out his *A Fourteen Week's Course in Natural Philosophy* in 1871. Fourteen weeks amounts to approximately three and a half months, or scarcely a full semester; this was a cram text. In this short course, Steele saw the purpose of a textbook to pass along well accepted knowledge.

> The object of an elementary work is not to advance the peculiar ideas of any one person, but simple to give such currently accepted facts as are believed by all. This plan affords no scope for original thought. The author has therefore simply sought to gather from every attainable source the freshest and most valuable information, and so weave it together as to please as well as instruct his pupil (Steele, 1871, p. 8).

Steele did seek to make his writing engaging, seeking to "please as well as instruct," but through a literary approach rather than an experimental one. In today's terms, Steele made physics *kid friendly* but without putting them into a laboratory. Such an approach is not vastly different than that of Bill Nye, the rather famous contemporary persona in a series of science education videos; students *watch* Bill Nye, they don't conduct his experiments.

Similar to other authors in the natural philosophy tradition, recitation formed a major part of Steele's instructional approach. Drawings and illustrations, included in the texts of Quackenbos and Peck to replace teacher demonstrations, served another purpose in Steele's texts as part of the recitation process. Students were not only to know definitions, but also to memorize drawings and be able to explain them in front of the class.

> When the subject of a paragraph is announced, the pupil should be prepared to tell all he knows about it. The diagrams and illustrations, as far as possible, should be drawn upon the blackboard and explained. Although pupils may, at first, manifest an unwillingness to do this, yet in a little time it will become the most interesting feature of the recitation (Steele, 1871, p. 9)

One such illustration is given below. Students would be expected to reproduce the essential details and explain how this illustration reveals the principles of hydrostatics. This was the sort of literary study later textbook authors would object to. However, it does appear that Steele hoped teachers would conduct at least some demonstration experiments for the benefit of the students. As he wrote, “The author will be pleased to correspond with teachers with regards to the apparatus necessary for the performance of the experiments named in the work (Ibid., p. 9). Perhaps in this Steele marks the shift towards making the study of physical science a bit more about experimentation, but overall for students the experience would still have been largely literary, hardly different in method than how they learned English, History or Mathematics.

Figure 9. A Man Using a Hydrostatic Pump. (Steele, 1871, p. 106)

Section Summary

This section sought to show how a number of textbooks from the middle of the 19th century reveal common characteristics of the *Natural Philosophy* tradition which dominated American schooling on topics of physical science during the period. It began with a work by Yale professor Denison Olmsted published in 1833 and included those by Richard Parker (1844), George Quackenbos (1860), Sidney Norton (1870), William Peck's adaptation of Ganot's work (1871), the popular work of J. Dorman Steel (1871). The purpose of reviewing these textbooks was to build an understanding of what the *natural philosophy* tradition might have looked like.

One can safely say that the tradition of *natural philosophy* remained strong until the end of the decade by long many of these texts remained in print. For example, Steele's text would be republished twice in 1878, once by American Books and also by A. Barnes, indicating its enduring popularity. Well's *Natural Philosophy,* first published in 1857 had already gone through fifteen editions by 1873. Despite this long run of success "almost without precedent in educational experience", it was completely revised in 1879 due to the "recent and extensive progress in scientific discovery, especially in the departments of heat, light, electricity, and magnetism" (Wells & Ford, 1879). Two European texts, written originally in French, were brought out in new American editions until the end of the decade (Arnott, 1829, 1853, 1879; Ganot, 1879). Based off these publication dates, natural philosophy remained strong as a curricular tradition until the 1880s when a new set of textbooks arose to challenge it.

Even after the new tradition of *physics* emerged, it is likely that copies of these textbooks remained in circulation and use as schools further from the larger cities lacked the resources to purchase new texts and the laboratory materials recommended by them. Add to that many established teachers may have been loathed to alter their instructional habits, or perhaps lacked the knowledge to do so the instructional tradition of *natural philosophy* was a very different tradition from that which would emerge in the 1880s and 1890s, and was much simpler to implement for teachers, especially at smaller schools. The same pedagogical techniques used in literature classes could be applied in teaching *natural philosophy* as the main source of authority lay in a textbook. Many did not require specialized knowledge by the instructor, priding themselves on being written in clear language, and under this tradition if any experiments were done at all, then only by the teachers. However, over the next two decades an increasing number of writers, inside and out of the classroom, began to urge the inclusion of laboratory work by students. While this emergence of the laboratory method began in earnest in the 1880s, in the next section we examine some early signs of what was to follow. By 1892 when the Committee of Ten convened in to draft a set of recommendations for aligning the efforts of schools and the expectations of colleges, the new tradition of physics had established itself as the new dominant ideal.

Early Stirrings (1872-1874)

Beginning in the 1870s one finds the stirrings of something new in the textbooks regarding how physical science was best taught. The first text examined (Cooley, 1872) was aimed at younger students and suggested very simple experiments; nevertheless, here teachers began to find a textbook recommending students do the investigating. Pickering's 1873 text shows how advanced the system of laboratory work had become at MIT. The model it provided of having multiple stations which students working asynchronously with each other would find favor with some later authors of high school texts (c.f. Gage, 1882). The distance, however, between one of the countries most advanced technical colleges and the ordinary high school was rather large. A secondary level textbook by Rolfe & Gillet (1874) shows what innovative practitioners were able to do at this early stage. Experiments were still intended as teacher demonstrations, but these authors encouraged their intentional inclusion at the start of each lesson as a means of putting natural phenomena first, and book knowledge or understanding second. The tradition of *natural philosophy* continued to dominate for the remainder of the decade as books published in the later part of the decade attest (Avery, 1878; Wells & Ford, 1879).

"The Simplest Experiments" (Cooley, 1872)

Even while the tradition of natural philosophy held sway, some stirrings towards a more scientific or investigative approach began to appear. Le Roy Cooley, Professor of Natural Science for the New York State Normal School, published a textbook in 1872 entitled *Natural Philosophy for Common & High* Schools which revealed a more applied approach to teaching physical science. Although still focused on presenting the "facts of Natural Philosophy," Cooley's intent was to achieve this aim by keeping the student in the habit of constantly "observing phenomena" and "drawing inferences" from what he observers (Cooley, 1872, p. 5). Cooley maintained that if a child's natural curiosity drove them to such questions as "What makes the thunder" they were ready to study natural philosophy. Certainly, Cooley's text was not aimed at advanced students preparing for college, the tone was not sufficiently academic for that, but he sought to offer schools a more engaging and authentic set of lessons.

Not only did Cooley want students to observe nature in order to satisfy their curiosity, he also felt schools should incorporate "the simplest experiments" which a student "may be able to repeat by himself" as these would "awaken enthusiasm" and provide "the greatest delights" (Ibid., p. 5). This attitude regarding how students ought to be spending their physical science lesson hours marked a real departure from the main tenets of the natural philosophy tradition. The first figure Cooley presents to his readers is that of a simple static electricity experiment using sealing wax and flannel (Figure 11). Not only is the first illustration of a simple experiment most teachers could conduct, and one students could perform at home, but it also starts the text off with one of the most fascinating and mysterious forces available: that of electrostatic repulsion, a topic normally saved until winter months.

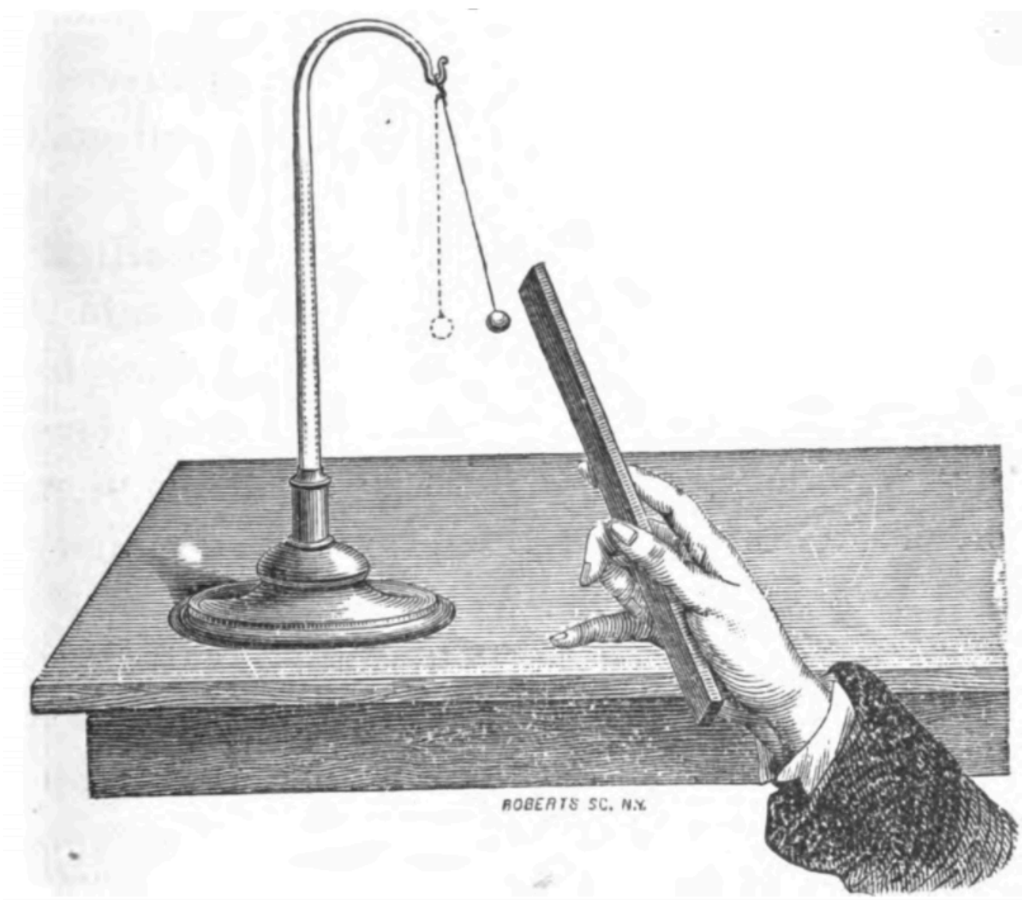

Figure 10. Simple Static Electricity Experiment Using a Stick of Sealing Wax, Flannel, and a Pith Ball (Cooley, 1872, p. 19)

Cooley did still emphasize the benefits of imparting "valuable facts" and developing "mental power" as others in the tradition did, but his approach diverged from other texts in seeking to teach students "*how to gain knowledge for themselves* by observing events" [original emphasis] (Ibid., p. 6). Cooley offered an instructional "plan" to help teachers achieve this greater aim. Teachers were to begin a lesson with "an easy experiment" to introduce the topic and to direct the students' attention to "certain appearances and conditions" allowing the student to "notice the truth which these appearances suggest" when called upon. The purpose was to teach students by engaging them in actual observations of the natural world and not just recall knowledge from a book. Another change Cooley made in his textbook was introducing new topics with a "question instead" instead of the "formal title" customarily found within traditional texts. By making this system of questions "easily caught by the eye," Cooley intended their use to subtract nothing from "the vivacity and vigor of the exercise" (Ibid., p. 7). Creating a dynamic lesson was clearly a part of Cooley's aim in publishing a new textbook.

Such an approach was often called "object teaching" and marked the "Oswego Movement" which received national attention during the 1860s and 1870s (DeBoer, 1991, p. 23). Led by Edward A. Sheldon, Superintendent of Schools in Oswego, New York, this movement sought to transform teaching into "an active process that required teachers to interact with the subject matter and which the children in a way they had not been accustomed to doing" (Ibid., p. 23). While promising impressive results, this approach to teaching created greater demands upon the teacher for as it became "a more personally engaging activity" it required of the teacher "a greater knowledge of his or her subject, greater skill in selecting materials of interest" and "greater skill in managing the variety of interactions" which resulted (Ibid., p. 24). A perennial challenge, if not the definitive challenge, of science education reform is that better instructional methods require more talent and energy from the teacher. If conditions do not attract and retain teachers with the required capacity and desire, then the best pedagogical approaches will continually fail. This is a lesson borne out by the history of science education.

"Conducting a Physical Laboratory" (Pickering, 1873)

Edward Pickering was professor of Physics at the Massachusetts Institute of Technology when he published *Elements of Physical Manipulation* in 1873. This book offered a complete course based on students conducting their own laboratory investigations. It was however, far beyond what secondary schools were capable of, and was intended instead to inspire other colleges and universities to follow its model (Kremer, 2011). Given that Clarke found only four school systems "offered a course in elementary physics with laboratory work" in 1880 (Rosen, 1954), it is clear that Pickering's work had slight influence on schools directly. However, it stands as an example of how laboratory work was being conducted at one of the country's foremost technical institutes and was certainly later used as a model to be adapted for the high school. In describing a list of required experiments for students applying to Harvard in physical science, Edwin Hall would name Pickering's text as one of four reference sources. Pickering's work thus merits examination as a model and source of inspiration for what high school courses in experimental physics might become.

Rather intriguing is Pickering's opening statement that "The rapid spread of the Laboratory System of teaching Physics, both in this country and abroad, seems to render imperative the demand for a special textbook" (Pickering, 1873, p. v). This must be taken as Pickering's rather optimistic sense that the new practice had spread to another of other Universities. Regardless, a textbook suitable for such use had been lacking and Pickering sought to provide it. In the introduction, he describes his method of "conducting a Physical Laboratory" at the Institute,

> Each experiment is assigned to a table, on which the necessary apparatus is kept, and where it is always used. A board called an indicator is hung on the wall of the room, and carries two sets of cards opposite each other, one bearing the names of the experiments, the other those of the students. When the class enters the laboratory, each member goes to the indicator, sees what experiment is assigned to him, then to the proper table where he finds the instruments required, and by the aid of the book performs the experiment (Ibid., p. vi).

Once a student had completed their assigned experiment, they would approach the instructor who could then assign a new experiment for the student to perform. This approach allowed a single instructor to superintend a class of twenty students, being free to circulate among the students to answer questions and correct mistakes. To differentiate the work based on student ability and progress, the instructor could match students with experiments of the correct difficulty level. As long as more equipment was set up than needed, the work flow could be maintained, and since equipment was not moved, the danger of breakage was greatly reduced, and time was saved.

“Thoroughly tested in the class-room” (Rolfe & Gillet, 1874)

A more academic book than that of Cooley, but similarly building upon the roots of the Oswego Movement was *Natural Philosophy for High Schools and Academies* by W.J. Rolfe and J.A. Gillet (1874). Based on Gillet’s experience as Professor of Mathematics and Physics in the Female Normal and High School of the City of New York, the “general plan and method” had been “thoroughly tested in the class-room by oral teaching” (Ibid., p. iii). Rolfe and Gillet were prompted to publish a new textbook to address two deficiencies found in “the elementary textbooks on Physics now in use,” namely being “sadly behind the times” and failing to “give any systematic development of the leading principles.” This was followed up by a quick survey of recent advances such as understanding heat as “a mode of molecular motion” and the “analysis of solar and stellar light” through the use of a spectroscope.

More interesting from the point of view of this discussion is how similar the instructional plan used by Rolfe and Gillet was to that of Cooley. Their method was to begin by “first establishing the fact by experiment” and “of then drawing out the principle” (Ibid., p iv). Experience had taught them that if, “each lesson be explained and illustrated with the class before being given out to be studied” the best results were obtained. This text did not yet make student laboratory work a central focus of the course as later texts would, however it is noteworthy that Rolfe and Gillet did recommend teachers perform actual experiments before the students. For even “the simplest experiments” and those requiring “the simplest apparatuses were “usually the best” for teachers to illustrating a topic with. Rolfe and Gillet’s efforts to provide “such experiments in all cases” indicates that they truly felt science instruction required an element of experimentation for as they saw it, “the principles of physical science are all established by facts of observations" (Ibid., p. iii). In this, the spirit of their instruction was much more aligned with the ideals promulgated science the scientific revolution. This is not to say their text did not contain a heavy dose of vocabulary and written descriptions of phenomena.

Section Summary

Taken together these works by Cooley (1872) and Rolfe & Gillet (1874) show some instructors had begun thinking differently about how to present the standard topics by advocating putting experimental demonstrations or even simple student exercises at the beginning of a lesson cycle. Cooley's work was geared towards the lowest and youngest students, not requiring much at all in the way of laboratory setup. Pickering (1873) was at the other end of the spectrum, instructing at the Massachusetts Institute of Technology, with a well-developed laboratory and advanced students at the collegiate level. Rolfe and Gillet sought more the middle ground, aiming their work at high schools and academies with an eye towards preparation for college. These then were some of the early stirring of what would become a movement around a new ideal of science instruction, known later as the laboratory method. The number of such instructors however was very limited during the 1870s. Certainly there were more than the few who wrote textbooks, but the number would still have been small. And yet, despite being just a few individuals, they were working out their ideas of how best to run student laboratories, acquiring experience in doing so and some publishing their results. In the following decade, these changes would accelerate.

Emergence (1880-1886)

In this section we begin to see the new ideal of student laboratory work begin to emerge. This goes beyond the simple illustrative experiments recommended by Cooley in 1872. During the early 1880s one finds evidence of far more rigorous experimentation being promoted in a new wave of textbooks beginning to wear the title *Physics*. Indeed, during this period, the phrase *natural philosophy* disappears from the covers of physical science textbooks. The trend to the new title had begun in the previous decade but came to completion during the 1880s. Aside from the title the most distinguishing feature of what emerged during this period was the emphasis on laboratory work. By the 1890s, the call for student laboratory work had at least become familiar. In this chapter we investigate this transformation by examining a series of textbooks as well as some of the relevant reports by both professional scientific and educational organizations.

A great deal of steam gathered during the decade as several new textbooks were published (Gage, 1881 & 1888; Trowbridge, 1884; Chute, 1889), as well as reports by the American Association for the Advancement of Science (AAAS, 1881 & 1888), Bureau of Education (Clarke, 1880; Wead, 1884) and the National Educational Association (1887). These publications indicate the rising pressure to integrate student-led laboratory exercises into the teaching of American high school physics. Growing dissatisfaction with how science was taught became apparent as both scientists and educators sought to transform the discipline from a book-study to a laboratory-based science. The concern was over how science generally, and physics specifically, were too often taught as a literary subject no differently than history or other subjects. Commissioner John Eaton in 1878 set in motion a series of national reports by professional educators and scientists.

Eaton published the report of Frank Wigglesworth Clarke in 1880. According to Clarke's report, the fault of the traditional approach lay in the failure to teach students the scientific spirit and method. Bearing Eaton's signature, the Report made the Commissioner's stance clear to all who read it. The approbation of the wider scientific community regarding the current teaching practices came out the same year in the report of the American Association for the Advancement of Science. These two reports launched a decade of criticism of American science education and efforts of teachers to address the issue. However, real change began with the publication of new textbooks which embraced the call for laboratory work. Little change could be hoped for until textbooks began to change, especially in a period where the main complaint was the excessive use of such books.

The publication of new textbooks written by physics teachers showed the awareness and response made by those in the classroom. The new textbooks emphasized student led laboratory investigations. While the texts differed in how this was best achieved, they agreed upon the need for students to investigate the phenomena of physics first hand. By the early 1890s, much had been written on the topic of how physics ought to be taught. A broad consensus emphasized the need for the subject to include laboratory work, but the nature of this work and its relationship with classroom lecture and book work remained unresolved. Many of the recommendations raised remain with us today as the modern subject began to emerge and take clearer shape. The scientific revolution may well have reached its zenith with the work of Newton two centuries earlier in 1687, but until the second half of the 19th century, it had not entered the American classroom. The rise of laboratory work in high school science marked its final arrival.

Science as a subject matter had been slowly gaining ground in the American curriculum, but until the rising emphasis in the 1880s on laboratory work performed by students, the subject remained another branch of literary studies. The fact that students in America learned science at all was fruit born of the Scientific Revolution. The rise of science in Europe, a phenomenon often referred to as the Scientific Revolution, is typically dated from the publication of Copernicus' *De Revolutionibus* in 1543 to Isaac Newton's publication of the *Principia* in 1687. The hallmark traits of science are its emphasis on direct observation and experimentation as a means of learning, in contrast to reliance on past authority. Yet, prior to the 1880s, very few physics texts focused on laboratory work as a key component of student learning.

Indeed, before 1875, few of the textbooks on the subject carried the term physics on the cover; most used the older term Natural Philosophy in their title (Cooley, 1869, 1872; Johnson, 1872; Norton, 1870; Quackenbos, 1860, 1871; Rolph & Gillet, 1874; Steele, 1871; Wells, 1873). This reflected a long-standing tradition of seeing the physical sciences as a branch of philosophy and as such dating back to the work of Aristotle, Thales, Pythagoras and other early Greek philosophers. Such a connection gave the field respectability during the centuries when education in Europe and later the United States emphasized culture based on the work of the ancient classical authorities. Textbook titles reveal a change beginning around 1875; by the 1890s few still spoke of Natural Philosophy.

"What Ought to Be" (Clarke, 1880)

In 1878, John Eaton, the Commissioner of Education sent out a circular to schools around the country, inquiring into their practices in teaching chemistry and physics. The work of writing up a report based on the returns (numbering over 600) was entrusted to Frank Wigglesworth Clarke, professor of Chemistry and Physics at the University of Cincinnati. The questions addressed a wide range of topics including "The history of instruction in chemistry and physics, the present, courses of study, the textbooks used, the value of apparatus, the laboratory facilities and policy, the character of examinations, and the cultivation of original research" (Clarke, 1881, p. 377). Clarke brought out his report in 1880, which was re-published and disseminated more widely in 1881. Clarke sought "to show on the one hand what is, and on the other what ought to be," revealing both "defects and remedies" and making it a rather rich and insightful document (Ibid., p. 377). The Commissioner of Education's actions, finding it sufficiently important to investigate, together with Clarke's efforts, revealed a new interest at the national level was awakening regarding how the sciences were being taught.

Figure 11. Frank Wigglesworth Clarke (1847-1931), Who Drew Attention to the Teaching of Physical Science (From *Sketch of Frank Wigglesworth Clarke*, 1898)

Among his positive results, Clarke's analysis found the teaching of physics and chemistry had become widespread. He was able to claim that, "Today chemistry and physics are taught in nearly all the academies and high schools of the land," a conclusion resting on reports, "from over one hundred and seventy cities" as well as "very much larger number of private schools and academies" (Clarke, 1881, p. 383). While real interest existed in incorporating student laboratory work into high school science classes, the realization of such interest was less than satisfactory. In only a few select schools did students have "laboratory practice" in both chemistry and physics. After pouring over the results of the survey, Clarke concluded that in most schools "mere textbook work" was being done with laboratory work limited to "only a few experiments being performed by the teacher" (Ibid., p. 384). This was hardly an ideal state of affairs.

Clarke did his best to appear an impartial judge. He described how "the usual critical methods" had been employed in "the selection of good and the rejection of bad material," with vague responses being counted as "no replies" (Ibid., p. 377). The bulk of the 200-page report consisted of descriptions of individual institutions and general statistics. Clarke drew here directly from the responses sent in and so claimed, "the fault lies not with the present writer" if the individual reports "have been inexact or incomplete, if some schools have claimed too much and others too little" (Ibid., p. 378). Finally, in those portions were Clarke added his own analysis, he explained they represented, "not merely his own personal notions" but were in line with those of "the greater number of specialists in physics and chemistry" (Ibid., p. 378). This was possible, Clarke felt, because there was general consensus around most of the matters.

However, Clarke found there was one area of wide contention. This was with regard to the proper sequence between didactic instruction and laboratory investigations.

> Upon one point, however, two schools of scientific teachers are in opposition; and here he has been compelled to choose sides. On the one hand it is believed that a

> full course of didactic instruction should precede the admission of students into the laboratory, and on the other it is held that laboratory and classroom work should go side by side from the beginning. The writer holds strongly to the latter opinion, he believes that much teaching of science preliminary to laboratory practice is like lectures upon swimming before the pupil enters the water (Ibid., p. 378).

Here Clarke felt drawn to advocate for one side, and to provide verbiage which would reappear in Gage's popular textbook which followed soon after. Clarke makes his reasons for this view clear: good science education required that it simulates the work of the professional as much as possible. This meant that it "should be so taught that the pupil may catch some of its real spirit, something of that feeling which animates and encourages the foremost investigators, and which alone is able to cause a vigorous growth" (Ibid., p. 378). In addition to making the course more relevant and engaging, such instruction also caused science education to fulfill its promise of teaching, "the scholar the experimental of grappling with unsolved problems". This was seen as one of the unique merits of science education and was a central reason for the push to increase laboratory work and run it concurrent with lectures.

The importance of science education for all students was built upon its relevancy to adult life and had much to do with the rising tide of industrialization occurring after the Civil War as the country struggled through reconstruction and then advanced into the age of monopolies, robber barons and the titans of industry.

> If culture and utility are both to be considered, we must recognize that some scientific training is indispensable. Nearly every pupil goes out of school into one

> of the great industries; and, whether he becomes a mechanic, manufacturer, railroad man, telegraph operator, farmer, miner, or tradesman, he is likely to encounter practical applications of the two sciences (Ibid., p. 384).

What such a world of work required of students was the knowledge that through "certain general principles" found to be "universally applicable" across all sciences each branch had "definite relations" to the others. Teachers needed to emphasize a vision of unity in which students would come to see each science as "a coherent whole" with "all its parts" as "vitally connected" by inculcating the "fundamental ideas" of each science, such as "the conservation of energy, the correlation of forces, [and] the conceptions of atoms and molecules" (Ibid., p. 384). Such an integrated perspective is indicative of the professional, who compared to the amateur is able to see the inter-relations of ideas and concepts.

Clarke identified two difficulties in the implementation of high school laboratories: qualified teachers and cost (Ibid., p. 379). The difficulty of securing competent teachers, Clarke felt, would have been some real issue twenty years earlier but by 1880 this problem was receding. The ranks of those qualified to teach laboratory sciences were swelling due to increasing "scientific studies" at the colleges and "improvements in the work of the normal schools" (Ibid., p. 379). Furthermore, "the establishment of summer courses of study" and "laboratories like the Woman's Laboratory in Boston" were also creating sufficient "supply" to equal "any demand which is likely to arise" (Ibid., 387). The general thirst for scientific training by adults in the late 1870s was simultaneously producing the staff needed to teach laboratory science in the schools.

The second was more imaginary than real, as much could be done with simple equipment. Clarke pointed out, as Gage would repeat, that much depended on the teacher. "If a teacher has the real scientific spirit, he can do a great deal with small appliances; but if his work is done in a perfunctory manner, then the best equipment in the world would help him but scantily" (Ibid., p. 386). Clarke found that "Many and many a school" had invested in "trifling electrical playthings" a sum of money which would have "gone far towards the establishment of a simple working laboratory" (Ibid., p. 386). Because of this, some schools had spent over two thousand dollars on "showy but almost useless instruments" while others had spent "not more than one tenth" the sum and yet were "actually doing good work in this direction" (Ibid., p. 386). If more complex equipment needed to be purchased, it could be bought directly from foreign manufactures due to a little known, special provision of congress not to tax scientific equipment with the usual import tariff.

Regarding the use of textbooks, Clarke maintained that books were not bad in and of themselves. In fact, "a good treatise" on either chemistry or physics "may be of great help to teacher and pupils" (Ibid., p. 385). Clarke warned of the dangers of "professional school-book makers" and of "text books written by amateurs, or by men who try to cover all the sciences" for such books "had best be rejected altogether" (Ibid., p. 385). This last comment seems a direct reproach of Quackenbos & Steele who, as previously mentioned, wrote on a variety of topics beyond science. Any teacher who was unable to determine the best manuals to use was to "seek the advice of the nearest specialist and follow it implicitly" (Ibid., p. 385). This opened the market up to authors who specialized in writing textbooks for a single subject area. The significance of Clarke's report rests on the extent to which it was seized upon by others, the most clear and vivid example of which was Alfred Gage who quoted Clarke directly as well as incorporating some of the central views into the Preface of his, *Textbook on the Elements of Physics* (Gage quoted but did not cite Clarke, citation being an uncommon practice at the time). The whole section of Clarke's Report regarding the furnishing equipment for the laboratory seems to have resonated strongly with Alfred for he used much of the same wording his Preface.

An "Outrage Upon the Minds of The Young" (AAAS, 1881)

At the same time as Clarke's Report was making waves (as will be seen by the direct borrowing by Alfred Gage), the American Association for the Advancement of Science brought out a separate Report at its twenty-ninth meeting, held in Boston, during August of 1880. The indictment of the current state of science teaching was harsh, and the words used choice. Authored by E.L Youmans, A.R. Grote, J.W. Powell, N.S. Shaler and J.S. Newberry, the Report was republished in 1881. Unable to provide the expected "digest of information" as to "what sciences were taught in the public schools, with what facilities and to what extent" the committee found the "nature and extent" of "certain radical deficiencies" needed first to be exposed (AAAS, 1881, p. 55). Admitting that the popularizing science was not among the founding purposes of the Association, the committee insisted the way "science is dealt with in the great system of schools" deserved the attention of the Association. Original research required "men prepared for the work" so it could hardly "be a matter of indifference" to the august body whether the work of schools did "favor or hinder" their work, whether science teaching aimed to "foster" or "thwart and repress" original thought (Ibid., p. 56). The Report amounted then to a vitriolic attack on the current state of science teaching.

Whereas Clarke's Report had make it clear the primary intention was to share the results of the Commissioner's survey, with no criticisms given in the bulk of the report; the AAAS

Report included no such data and focused instead on pointed out the flaws of the current system. The first trouble the Association found with science teaching in 1880 was "the old ideal of school" as "a place where knowledge is got from books" (AAAS, 1881, p. 59). This "regime of book-study" had caused science teaching to be "carried on by *instruction*" with students being "filled up with information" rather than "taught to think for himself" (Ibid., p. 59). What science education ought to do, according to the committee, was to cultivate "the observing powers" and "stimulate inquiry" causing students to exercise "judgement in weighing evidence" and so form "original and independent habits of thought" (Ibid., p. 59). However, since science was "commonly pursued in book descriptions" the knowledge it offered was "an illusion and a cheat" (Ibid., p. 59). Then followed the harshest, most scathing criticism. "All eminent scientific men" had "condemned" the current mode of teaching science as a "deception" a "fraud" and an "outrage upon the minds of the young" (Ibid., p. 59). The committee made their views very clear.

Following this tirade, the committee delved deeper into matter. After the attack on the overuse of textbooks, the committee aimed their fire upon "object lessons". The method of "object teaching" (or of using objects such as specimens to stimulate student curiosity) had been "extensively introduced" into the primary schools with the intent of "cultivating the powers of observation" as "a beginning in science" (Ibid., p. 60). In the opinions of the committee, "Nothing is gained educationally by barely having an object in hand when it is talked about" and so such lessons while not "useless" were not "the A B C of science" and so had "not yielded what was expected of it" (Ibid., p. 60). Just as object lessons had become popular as a false hope for improving science teaching at the primary level, "oral-teaching" had caught on as a pseudo-scientific method in the eyes of the AAAS committee.

This method amounted to “instruction without a textbook”, a method which seemed “fair” but proved “delusive” (Ibid., p. 61). Rather than replacing the textbook with natural phenomena, it simply put the teacher in its place and brought students no closer to a true study of science. Born of the notion that “the teacher is the school (a German maxim) the intent of the “live system” was to give “animation” to learning, but instead it merely substituted “superficial class-activity” for the “deliberate work of the individual pupil” (Ibid., p. 61). In some ways the method was indeed a step backwards, for the work of the teacher displaced not only that of the book but also that of the student. The committee lambasted teachers. “Oral-teaching implies a fertility, a versatility, and a proficiency in scientific knowledge on the part of teaching which that class of persons does not possess” (Ibid., p. 61). As a result, “textbooks are filtered through the very imperfect medium of the ordinary teacher’s mind, and the pupil has nothing to do but to be instructed”; in consequence “every sound principle of education” became “outraged” and science “made ridiculous” (Ibid., p. 61). Having dispatched two popular improvements over the textbook method, the committee trounced the very nature of the public-school system next as being incapable of developing scientific thought in its current configuration.

The real trouble was “deep in the constitution of the public schools” which had become “an elaborate mechanical system” (AAAS, 1881, p. 61). There is some irony in it being the American Association for the Advancement of Science which identified the schools with a sort of inhuman machine. Science, together with technology, had spawned the industrial revolution and saw to the rise of both factories and machines. And yet the AAAS committee attacked schools for subordinating teachers and learners to the system and its “machine work”, recognizing that “machines make no allowances” (Ibid., p. 61). The scientists recognized the individual differences in “capacity, aptitude, attainment and opportunity” among students which ought to be “the prime data of all efficient mental cultivation” (Ibid., p. 61). As the committee saw it,

> The exercise of original mental power or independent inquiry is the very essence of the scientific method and with this the practice of the public schools is as war. Moreover, a system which deals with the average mind and does not get at the individual mind breaks down at the point where all true education really begins, that is, in promoting self-culture” (Ibid., p. 62).

The committee recognized that “many exceptional teachers” did what they could to promote science in the “true spirit” while the multitude of instructors groped after something better (Ibid., p. 63). The solution was to provide this multitude with “the best modes of improving the teaching of science in our public schools” (Ibid., p. 63). The authors of the report ended by asking the Association to assign a committee to do just that, a committee that published its report in 1888 by which point much had transpired.

“To Interrogate Nature with His Own Hands” (Gage, 1882)

Figure 12. Simple Experiment for Students to Conduct, Demonstrating Atmospheric Pressure (Gage, 1882, p. 2)

Alfred Payson Gage heard, and first answered, the clarion calls of Clarke and the AAAS. Just two years after Clarke published his findings, and a year after the AAAS report, A. P. Gage (1882) brought forth a *Textbook on the Elements of Physics, for High Schools and Academies.* The language used by Gage makes it very clear he had read and was responding to Clarke’s writing. The 1882 textbook would be the first of a series of works for Mr. Gage; new titles were published by him every few years (1884, 1888, 1890, 1892, 1893, 1895, 1898, 1902). An instructor in physics at the English High School of Boston, Massachusetts Gage launched himself into the efforts to bring experimentation to the foreground of student’s experiences. Alfred had clearly read Clarke’s report, but if he had read that of the AAAS, he seems not to have embraced its dismissal of the object teaching. Gage opened his preface by citing Mr. E. P. Seaver, Superintendent of the Public Schools of Boston, “It is a cardinal principle in modern pedagogy that the mind gains a real and adequate knowledge of things only in the presence of the things themselves" (Gage, 1882, p. iii). Having laid out the general acceptance of "object-teaching" Gage made his support clear, "This unequivocal language, from the pen of one of our foremost educators, faithfully and forcibly reflects the sentiment of the age, and leaves nothing further that need be said in advocacy of object or inductive teaching" (Ibid., p. iii). Gage had clearly made a connection in his mind between the object method and the inductive one.

While he felt no need to further advocate for inductive teaching, Gage had much more to say regarding the implications for the teaching of physics. One of the first successful writers of laboratory-based textbooks for physics, Alfred used his Preface as a platform to challenge and exhorting his readers (presumably teachers of science) to take a more direct approach in teaching physics to students.

> Shall the teacher manipulate the apparatus, and the pupil act the part of an admiring spectator? or, [sic] Shall the pupil be supplied with such apparatus as he cannot conveniently construct, always of the simplest and least expensive kind, with which he shall be required, under the guidance of his teacher, to interrogate Nature with his own hands? (1882, p. iii).

The wording of the second question makes it clear which approach Gage favored. Any doubt is dispelled by his continued passionate series of questions, asking, "by which method will he acquire the most vigorous growth," and which leads the students to "catch something of the spirit which animates and encourages the faithful investigator?" (Ibid, p. iv). Gage desired students to do more than merely pass an exam or to know the "essential" aspects of physics which "every well-read person" ought to know (Steele, 1871, p. v), but rather sought to spark the spirit of student inquiry.

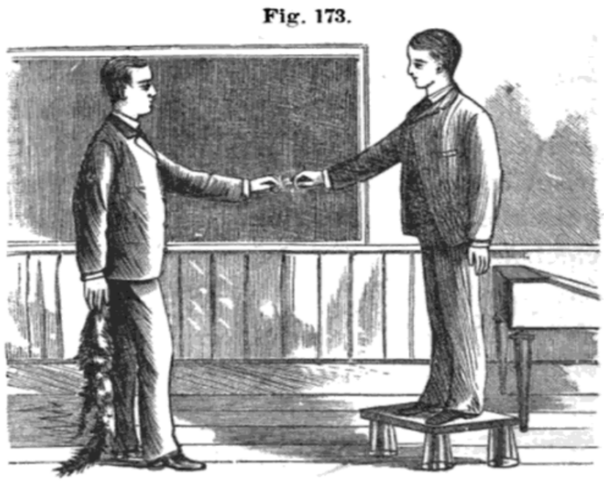

Figure 13. Two Students Demonstrating Static Discharge, With Simple Equipment (Gage, 1882, p. 327).

The examples which Gage draws upon in seeking to persuade his readers are telling. Expanding his argument with a parallel from medical teaching Alfred asked, "Can elegantly illustrated works and lucid lectures on anatomy and operative surgery take the place of the dissecting room?" (Gage, 1882, p. iv). Returning to education generally he asks, "Have lecture-room displays proved very effectual in awakening thought and in kindling fires of enthusiasm in the young?" before tacking back again to drive home the centrality of experimentation in stimulating scientific curiosity, "Or would a majority of our practical scientists date their first inspiration from more humble beginnings, with such rude utensils, for instance, as the kitchen affords?" (Ibid., p. iv). His exhortation of student led experimentation became even sharper and more acerbic, “Is the efficiency of instruction in the natural sciences to be estimated by the amount of costly apparatus kept on show in glass cases, labelled "hands off," or by its rude pine tables and crude apparatus bearing the scars, scratches, and other marks of use?” (Ibid., p. iv). Gage clearly preferred a style of physics instruction which emphasized direct student experimentation even with simple equipment over high-minded lectures and fancy demonstrations as the latter put students into a passive role.

After this robust call to put lab equipment in the hands of students, Gage addresses some of the perceived challenges towards its implementation. From Gage’s perspective “the usual, and almost only reason given, is ‘on account of the expense’” and excuse he felt rested “upon the flimsiest of foundations” (Gage, 1882, iv). In his own work he managed to furnish his lab with three hundred dollars, while “many and many a school” had wasted money in “showy but almost useless apparatus” the cost of which would have gone a long way towards equipping “a simple working laboratory” (Ibid., p. v). The real deciding factor Gage argued was the teacher, “If he has the real scientific spirit, he will do a great deal with small appliances; but if his work is done in a perfunctory manner, then the best equipment in the world will serve him but scantily” (Ibid., p. v). Here emerges one of the persisting questions of physics reform, namely why after five quarters of a century of efforts to improve physics education at the high school level are so many of the challenges persisting? Why do current reforms, such as those embodied in the *Next Generation Science Standards* still emphasize the need to shift, “from a focus on knowledge itself to a focus on putting that knowledge to use” (NGSS Lead States, 2013, p. 375)? Are these challenges driven by some deep-seated, intractable and eternal limitation, or are they surmountable on a system-wide level? Can and will America see high quality physics instruction flourish around the country accessible to all students in all its high schools?

Having identified the teacher as the central factor in limiting or achieving successful introduction of laboratory exercises for students, Alfred began a discussion on pedagogical procedure. First, should laboratory work precede instruction or vice-versa? In alignment with his previous espousal of inquiry and active investigation, Gage held that, "So far as practicable, experiments precede the statements of definitions and laws, and the latter are not given until the pupil is prepared, by previous observation and discussion, to frame them for himself" (Gage, 1882, p. v). To keep them in "the proper channels" students ought to be guided in their investigations "by the book and by blackboard directions" (Ibid., p. vi). A rather memorable motto followed, "Do not teach pupils to swim before entering the water" (Ibid., p. vii). A second question regarded class-size; Alfred found very small class-sizes crucial, with fifteen students to be, "about as many as one teacher can care for successfully" (Ibid., p. vi). A third question regarded whether students ought to all work on the same experiment or on different ones. To cut down on equipment costs, Gage favored using stations with three set ups of each experiment. Given fifteen students, this allowed each student to perform five experiments in a single class period (which suggests something of the simplicity of investigation). One can then summarize the system of physics instruction which Alfred Gage set out in 1882; it emphasized direct, if simple, experimentation by students who rotated through a series of experiments, with direct instruction and discussion following after direct observation and investigation.

To "Read Nature in The Language of Experiment" (Avery, 1884)

That the proponents of inductive teaching methods had an impact on the changing mindset of others, can be seen in the work of Elroy M. Avery. Avery was the Principal of the East High School in Cleveland, Ohio and author of a series of science textbooks. His *Physical*

Science Series included two textbooks on physics and two on chemistry (Avery, 1884). Avery's work shows a transition from the earlier tradition in which Natural Philosophy was taught as a branch of knowledge through didactic means (definitions, recitations, and book study) towards a more experiment-based approach. In 1878, two years before Clarke's report, Avery's *Elements of Natural Philosophy* was published. The subtitle indicates its audience, namely high schools and academies. The first illustration on the first page is not of a piece of scientific apparatus, but rather Avery presents to students "an outline map of the wide realm of human knowledge" (Avery, 1878, p. 1). This illustration shows a branching classification of all knowledge into smaller and smaller categories in which physics is one among the sciences dealing with matter and force. The text opens with an introduction using metaphorical language of a student surveying human knowledge from a mountain top before descending into the plains. After this short literary opening, definitions follow beginning with. Physics is thus portrayed as a rather static branch of classified knowledge, the result of previous achievements rather than an ongoing process of discovery.

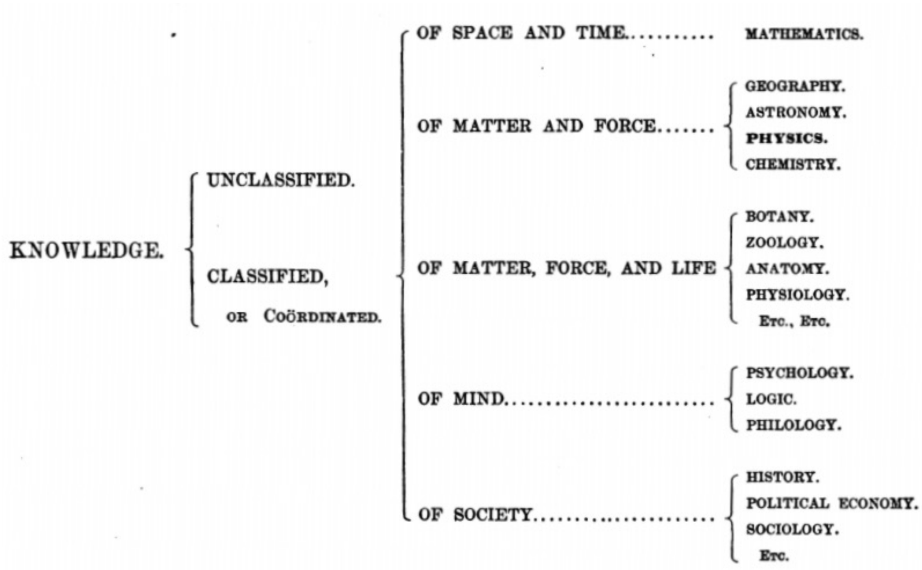

Figure 14. Physics as A Branch of Classified Knowledge (Avery, 1878, p. 1).

Six years later in 1884 (and four years after Clarke's report) Avery published his *First Principles of Natural Philosophy*. There is a dramatically different approach in this text, beginning with an opening quote on the first page, "Read Nature in the language of experiment" (Avery, 1884, p. 1). The quote is followed by descriptions of two simple experiments, watching air resist the inrush of water as a glass is submerged and attempting to make two objects, starting with one's hands, share the same place at the same time. Both experiments are followed by bold text stating the principle demonstrated. "Air and water cannot be in the same place at the same time" is the conclusion illustrated by the first experiment, while the second showed that "no two things that you can handle can be in the same place at the same time and that every one of them takes up room" (Ibid., p.1). This marks Avery's attempt to revise his textbook to incorporate the inductive method. Yet the book soon returns to the same definitions found in the 1878 *Elements*. The following year, in 1885, the *Elements* were republished with no modification towards a more inductive approach, indicating that Avery was expanding his offerings rather than progressing beyond his earlier didactic style. Both textbooks by Avery during this period used the older term "natural history" which was losing favor during the 1880s. Avery can be seen as an author who spans the transition period between the didactic texts of the 1860s and 1870s and those using either an inductive or deductive laboratory-based approach which arose during the 1880s.

"To Stimulate the Love of The Truth" (Wead, 1884)

In 1884, the Commissioner Eaton requested the Acting Secretary of the Interior M.L. Joslyn publish a follow up report to that of Frank Clarke four years earlier. The permission was duly given, and the "very satisfactory work" by Charles K. Wead was published that same year (Wead, 1884, p. 573). The suggestion that the Bureau of Education could "efficaciously" collect the "numerous facts and opinions" regarding the teaching of physics which could then be acted upon by a joint committee from both the American Association and the National Educational Association had come from T.C. Mendenhall. In response to Mendenhall, Eaton had sent out the circular and inquires in 1883, turning over the responses to Wead. What resulted was a deep espousal of the inductive method of teaching. While the bulk of the two-hundred-page report was spent detailing the responses, it also spent a considerable number of pages detailing what the inductive method was. The report notably distinguished between fives ways in which "the mind acquires new truth, namely: observation, induction, deduction, experimentation, and dogmatic statement" (Ibid., p. 578). Charles Wead in championing the inductive method pointed out it was "a most unwarranted conclusion" to assume that the presence of laboratory work indicated the adoption of inductive teaching. Perhaps unsurprisingly, the report also identified Gage's *Elements of Physics* as "the most conspicuous example now in the market of this inductive method" (Ibid., p. 686). Gage's text had gotten national attention.

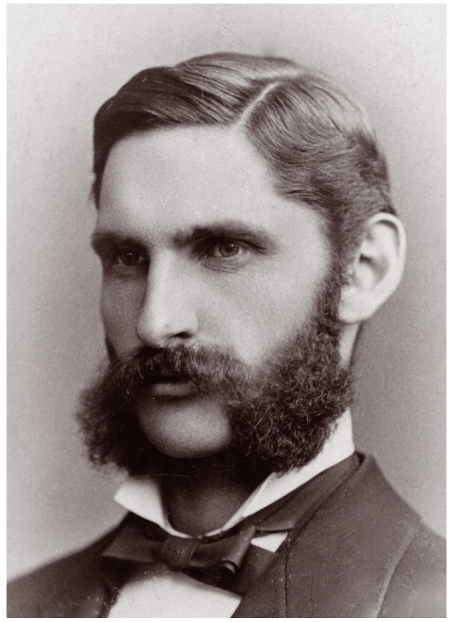

Figure 15. Charles Kasson Wead, Who Espoused the Inductive Method in His 1884 BOE Report. (Accessed at https://www.lib.umich.edu/faculty-history/faculty/charles-kasson-wead)

Wead began by citing the 1878 circulars upon which Clarke had found "the most serious diversity...serious not because of the diversity, but because of the ignorance either of the subject or else of its proper place in education" (Ibid., p. 575). Thus, Wead made it clear that similar to Clarke his task was, "not to prescribe or advise how and when physics should be taught, but to...help the teachers of this country toward clearer and more uniform views on these points" (Ibid., p. 575). He sought to bring clarity and coherence to the discussion. Wead also made it clear he felt that the real questions regarding the sciences in secondary education were *"how* they should be taught" and "what ends they should subserve in education" rather than simply if they deserved to be included (Ibid., p. 575). Although striving not to "prescribe or advise", the report often did sound much like such (Ibid., p. 575). This was because the opinions of the responders were so similar. While the quality of Wead's reporting was high, the representation was far from complete. The number of responses were considerably less than six years earlier, as only seventy replies (not six hundred) came in, and of these only thirty-one responses were from secondary school. All but three of the school responses came from the Eastern Seaboard, the three exceptions being Ohio, Indiana and Tennessee.

By summarizing the opinions of those physics teachers who bothered to reply, Wead was able to give a consensus opinion on several matters. The net effect of the report was to heavily promote inductive methods of teaching. As Charles Wead explained, that while the report might appear biased, it was only that he had been unable to find "a single article" in print which "advocates what may be called, for want of a recognized name, the non-inductive, dogmatic, or didactic method of teaching, and points out the limitations and difficulties of the inductive method" (Ibid., 576). As we see later, the opposition to inductive methods were forth-coming, but in 1884 the favor was all for adopting inductive teaching methods. Charles made it clear that that "scarcely any writer" thought one could or should use exclusively one method of instruction (Ibid., 576). The key question was "what should be the *main* or *primary* object of the work", should it be mainly inductive or mainly deductive or mainly didactic (Ibid., 576)?

In order to clarify certain points in the discussion, Charles Wead set out some useful distinctions and definitions. For his report "high school" included "academies, seminaries, preparatory schools, and all other secondary schools" (Ibid., p. 578). Wead the sought to separate "laboratory work" from the "inductive method" for conflating the two was "a most unwarranted conclusion" (Ibid., p. 578). Inductive reasoning required students to seek the "cause, principle, or law" which arose from "the observed phenomena" which did not necessarily follow from all laboratory work (Ibid., p. 578). Laboratory work, Wead found, referred to a wide range of activities including students making instruments or devices, conducting qualitative experiments based on textbooks, higher, more quantitative measurements, and even teacher demonstrations in which students passively watched.

In discussing the results of the survey, Charles Wead found “the weight of opinion is decidedly that at first the teaching should be inductive” despite acknowledging that some felt induction and deduction could not be “unassociated” and that others felt its difficulties were “insuperable” (Wead, 1884, p. 683). Foremost among these difficulties was the unfamiliarity of the method for most teachers had “probably known little or nothing of it in his own education” (Ibid., p. 683). Then there was the slow “progress of the students following this method”, and finally “the common advocacy of scientific studies for the value of their information” made it challenging to teach physics in a way that promoted thinking over knowing (Ibid., p. 683). These were and continue to be challenges faced by attempts to improve science instruction in America’s schools.

Given that the first challenge mentioned above was “the most serious” but not “inherent,” Wead tackled it first by laying out a more detailed discussion of the method (Ibid., p. 684). Acknowledging that the deductive method could be carried out in a way that emphasized four of the five ways of knowing (excluding induction), with results “not valueless” (Ibid., p. 684). Too often, however, too much was given away by the book or the teacher, leaving “the pupil’s thoughts” unstimulated and the work “entirely dogmatic” (Ibid., p. 684). The inductive method in comparison stressed the “name-giving, vitalizing thing” which was “the induction of the principle or law by an active mental operation, instead of the passive reception of it from authority, or from a priori considerations, as the ancients did” (Ibid., p. 684). The description which followed clarified greatly what Wead considered to be the scientific method of obtaining new knowledge.

> Following the scientific method, we first observe the phenomena sharply and then seek for a cause or for the law according to which the forces act. A dozen guesses may be made quickly, perhaps to be found insufficient. But, if the guess is a definite one, definite conclusions (deductions) can be drawn from it which will lead to new observations or experiments. Perhaps our supposed law is immediately disproved; then we make a new guess and so continue until one explanation remains that is consistent with all our knowledge and stands all the tests we are able to apply; and now is the time for us to consult the published record of other men's experiments and in this way learn those facts that are otherwise unattainable by us (Ibid., p. 684).

If students were expected to follow such a complete process of discovery, one can see why teachers would increasingly complain of the time the inductive method took. Students were to work forward from a phenomenon, seeking hypotheses to explain their observations, design and conduct their own experiments to obtain new results and observations, continuing the process until they had accumulated both a body of knowledge and an explanation which match it. Book learning was merely the final step in Wead's idealized process, taken only after all more immediate resources had been consumed.

As if anticipating the possible opposition to the method his lengthy description drew, Charles Wead continued by extolling the merits of the inductive method. Inductive training was "pre-eminently fitted to discover the truth, to stimulate the love of the truth" and because "we must use inductive methods all our lives" (Ibid., p. 685). Another reason to prefer the method over quicker approaches was that "in the opinion of many teachers more of can be taught so as to be remembered in this way than in any other" (Ibid., p. 685). While slow, the argument went that the inductive method led to better retention and so more was remembered despite less material having been covered. Given "the limited time, maturity, and mathematical preparation of the students in our schools" Wead rhetorically asked if the method could be used with "much value" in studying physics (Ibid., p. 685). "Nearly all the writers of the replies advise [sic] it" was the answer (Ibid., p. 685). Wead concluded this defense of the method by claiming that the inductive method was really the beloved Socratic method "put in a form suitable for teaching" (Ibid., p. 685). Thanks to Plato, the place of Socrates as the questioning genius had been secured in Western Philosophy for thousands of years. The irony of an advocate of inductive reasoning ultimately making a final pitch based on authority could not have been lost on all of Wead's readership.

Charles Wead then turned to the topic of textbooks, and their proper place in physics instruction. Textbooks "of the ordinary kind" were according to Charles Wead "almost fatal to the scientific method in schools" (Ibid., p. 686). The key here was to avoid the use of ordinary textbooks. There were some exceptions. Wead approved of a plan proposed by a Mr. Osbun to develop textbooks where the experiment was given in one column, and students need to complete a second and third column with their observations and inferences, but the book had not yet been completed. Charles Wead singled out Alfred Gage's textbook as the best example of a book written to support the inductive method. The reason for this was the way in which experiments preceded the statement of laws or principles and the "many questions" connected with each experiment which led students to be "active, not passive" and to "think for himself before the answer is given" (Ibid., p. 686). While admitting that teachers could "dispense entirely" with books, Wead pointed out that much time could be saved using another plan, namely providing students with "cheap leaflets" that contained the instructions for laboratory work (Ibid., p. 686). Such sheets might cause more teachers to try the inductive method early in the year, before switching back to the textbook, negating "the opposition of the conservative class" since textbooks were still used (Ibid., p. 686). Obviously, there remained a strong preference for the use of the textbook method in some corners, a reality which Charles Wead acknowledged.

> Laboratory work is favored by the great majority, though sometimes by this expression is evidently meant merely demonstration by the teacher and sometimes the meaning is doubtful. Unfortunately, few teachers can speak of the results of this kind of teaching, it has been tried so little, except in the normal schools; in these, of course, the end is (in part) professional, and the work would be likely to be different from that best suited to the average student (Wead, 1884, p. 130).

This passage gives the clear sense that by 1884 very few teachers had adopted the laboratory method. While few were already teaching according to the newly emerging tradition of physics, the basis for doing so were being laid, and within ten years, the sense would be reversed (Carhart and Chute, 1892).

"The Scientific Habit" (Trowbridge, 1884)

In the same year as Professor Wead published his praise of the inductive method, Professor Trowbridge of Harvard University published a textbook entitled, *The New Physics*

(1884). The work amounted to both an alternative to and an attack on the tradition of *Natural Philosophy*. The title itself indicates that Trowbridge was quite aware he was promoting something new and was seeking to distance his textbook from the bulk of those that preceded it. The subtitle indicates both that Trowbridge was a proponent of the "experimental study" of science, which was just beginning to emerge as a new ideal of science education, and that his book was intended for use in "High Schools and Preparatory Schools." Trowbridge's textbook represents the new tradition of physics instruction from the perspective of an elite specialist in the field. As physics sought to emerge from this tradition, advocates like Trowbridge not only sought to redefine how physical science was taught, but also pushed for longer and deeper studies of physics in secondary schools. Under the tradition of natural philosophy knowledge of the natural world was seen as a matter of enrichment, and not as a core content area (Greek, Latin and Mathematics remained the center of the curriculum until the last decades of the century) and so proponents of physics not only fought for student laboratory work but were also still working to increase its share of the overall school day.

Trowbridge began his preface with an indictment of non-laboratory methods, writing in the third person to gain objectivity in the eyes of his readers, for "those who have made a careful study of the methods of instruction" and had judged the methods based on "the intellectual training manifested by students" found "unfavorable" the results of "the lecture or recitation system unsupported by laboratory work" (Ibid., p. iii). Following this this initial salvo against the status quo, Trowbridge then pushed for a more extended study of physics by comparing the acquisition of skill in physics with that of skill in language. Both required "long and persistent exercise of the mind" in order to stimulate "intellectual growth." In doing so Trowbridge artfully played off the polemics justifying the continued study of Greek and Latin in the American high school, namely that such extended study exercised the mental muscles. By comparing “the scientific habit” with the “literary habit of mind”, Trowbridge argued for example that both required years of effort but were equally deserving of “cultivation” (Ibid., p. iv).

After expounding on the value of deepening the physical science curriculum, Trowbridge used a figurative teacher to admit that the “method of lectures and recitations” common to the natural philosophy tradition yielded but “comparatively small results” (Ibid., p. iv) before addressed two of the most common objections to more laboratory work: time and money. The time required could be gained by spending less of it on lecture and spending it in the laboratory instead; costs could be brought down by using “cheap apparatus” with which more could be done than “generally supposed.” Trowbridge’s intended result was to “put in the hands of the teacher” such a manual as would do for physics instruction what the “excellent manuals in chemistry” had done for its instruction (Ibid., p. v). In addition to the emphasis on experimentation, Trowbridge also paid attention to the arrangement of lessons so as to bring out the “logical connection” between them and emphasize how certain concepts such as “the doctrine of the conservation of energy” could be applied to unify apparently disparate phenomena. Revealing “the tendency of physical science today,” namely experimentation and the search for unifying concepts and fundamental principles, is what made Trowbridge’s textbook exemplify “the new physics” (Ibid., p. v).

Trowbridge, a practiced experimenter in physics, delivered on his promise to provide teachers with a textbook filled with simple experiments. Figure 17 shows a data table to be used by students and incorporated into the text. The experiment involved students estimating the length of a twisted piece of wire using several straight samples, and also calculating the error in their measurements by comparing them with their average. This experiment, found on page 8 of his textbook, was already the eighth experiment of the book. While the experiments remained fairly simple to reproduce, the mathematics Trowbridge used to express the concepts involved were far more advanced (Figure 18) and may have limited the utility of his textbook to schools with elite students. In terms of mathematical requirements, Trowbridge and Gage stood worlds apart.

NO. OF WIRE.	L, length in cm.	W, weight in grammes.	$\frac{W}{L}$, weight of 1 cm.	W, calc. wt. of wire.	E, error of W–W.′
No. 1.					
No. 2.					
No. 3.					
No. 4.					
No. 5.					
No. 6,					

Figure 16. Data Table for a Simple Experiment Incorporated into Textbook. (Trowbridge, 1884, p. 8)

If the moment of inertia of the wheel and axle $= \frac{G y^2}{g}$, its inert mass reduced to $B = \frac{G y^2}{g a^2}$, and we then have

$$M = \left(P + \frac{Q b^2}{a^2} + \frac{G y^2}{a^2}\right) \div g$$

$$\frac{P a^2 + Q b^2 + G y^2}{g a^2}.$$

Or the acceleration of the weight P

$$= \frac{\text{moving force}}{\text{mass}} = \left(\frac{P - \frac{Q b}{a}}{P a^2 + Q b^2 + G y^2}\right) g a^2.$$

$$= \left(\frac{P a - Q b}{P a + Q b^2 + G y^2}\right) g a.*$$

Figure 17. Sample Calculation from Trowbridge's *New Physics* (Trowbridge, 1884, p. 125).

"The Pupil Performs His Own Experiments" (Worthington, 1886)

Only two years after Trowbridge published his *New Physics*, A.M. Worthington brought forth *A First Course of Physical Laboratory Practice* (1886). Worthington was the Assistant Master at Clifton College and drew upon, "several years' experience in conducting large laboratory classes" in producing his textbook (Ibid., p. 1). His object was "encouraging the teaching of Physics in schools, especially by means of laboratory work, in which the pupil performs his own experiments" (Ibid., p. 1). This text was a follow up to a shorter volume published a few years earlier along the same lines. After stating his purpose, Worthington addresses some of the resistance others have expressed in Wead's report to student laboratory work.

In particular he addresses the erroneous notion that because young students were "unqualified" for lab work their results would by force be so "slovenly" and "inconsequent" that students who be "disgusted" by their "unsatisfactory" work (Ibid., p. 1). Worthington's work at Clifton had been "confined to boys…of about the ages of fourteen to seventeen" (Ibid., p. 3), and he leverages this experience to making it clear that even students at the secondary level were competent to do lab work. Based on working directly with students in a laboratory setting, Worthington was able to claim that his students were "encouraged by feeling that an accurate result is within his reach if he takes sufficient pains" and that experiments could be chosen which would yield results "sufficiently accurate to suggest or confirm the correctness of the principle involved" (Ibid., p. 2). Worthington found it important that although the student's "standard of accuracy is a low one in comparison with a trained Physicist" that students be given "an early opportunity" for "natural growth" for "precision in all attainments grows gradually with practice and increasing mental power" (Ibid., p. 2). He cited the vast difference between "the games of young children" and those same games "as played by men!" to underscore his point (Ibid., p. 2).

This point being made, Worthington delves into the purpose of laboratory work. For instance, the point of making measurements was not to show students how to make them "*most accurately"* but rather to give them "a clear idea" of what "such measures *mean*" (Ibid., p. 3). Hence, he preferred to avoid such "corrections" as "would obscure the main issue" for after all this was to be learning by doing (Ibid., p. 3). Worthington also realized that most of his students would not go on to become specialists in the field. For this reason, the experiments ought to aim at being "instructive" rather than "accurate" as the point was not "of training up Physicists" but rather "of evoking in the boys a genuine and generous interest in natural phenomena" (Ibid., p. 4). By arousing a "serious interest" in a large number of youths, the "future excellence in the few who may afterwards become specialists" was assured (Ibid., p. 4). To further develop students' sense of agency, Worthington had students work in pairs, but allowed them to follow their own pace with the result that some got on "much faster than others" (Ibid., p. 6). He encouraged this as "it makes each boy feel that his progress is in his own hands" and simultaneously "renders it unnecessary to keep apparatus enough for all", thereby driving down costs (Ibid., p. 6).

Section Summary

In this section *physics*, begin to emerge from its predecessor as a new instructional tradition. The story was traced by taking a closer look at the report written by Frank W. Clarke at the behest of the Bureau of Education. Shortly after this report the American Association for the Advancement of Science also entered into the discussion. While the educators and scientists did not agree on all points, they did agree that the state of teaching in physical science left must to be desired. Foremost among the complaints by both the educators and the scientists was that there was too much rote memorization and not enough practice of key scientific habits such as found in laboratory investigations. Alfred Gage published his very successful textbook shortly thereafter and clearly borrowed language from Clarke's report. Quickly other textbooks entered the market, each emphasizing student laboratory work (Avery, 1884; Trowbridge, 1884; Worthington, 1886). Professor Wead published another report on the behalf of the Bureau of Education amplifying the conversation Clarke had begun. Wead emphasized the importance of inductive reasoning, and desired students to learn how to think and reason just as professional men and women of science did. In the next section, and the division is arbitrary, we continue to follow the embracing of the laboratory ideal by those interested or invested in physical science education.

Growth (1886-1889)

Harvard implemented an alternative Physical Science entrance exam for those students who sought admission in 1887. Certainly, the number of American students this affected directly was limited. Compared with the number of graduating seniors, few students then, as now, apply to Harvard College and furthermore, graduating seniors were themselves the exception rather than the rule. And yet Harvard's creation of an experimental laboratory-based examination for admission set a new bar for America's students. Under President Elliot's guidance, Harvard became one of the country's premier universities and taken as a model for other institutions looking to increase their reputation. Also, while the number of students who applied may have been relatively small, these were some of the ablest students in a classroom and so gained the teacher's attention. If a school wanted to increase their relative standing, one clear way to demonstrate the quality of one's instructional offerings was to showcase the number of college admissions received. This set up a system of schools seeking to meet the demands of colleges despite the small percentage of students seeking college admission, a system which amplified the importance of the Harvard Descriptive List.

"Exhibited Numerically, Graphically, Or in Tabular Form" (Harvard, 1886)

Published in 1886 as the *Provisional List of Experiments in Elementary Physics for Admission to College in 1887,* were a set of forty laboratory experiments which would become known as the *Descriptive List*. The lengthy title made the purpose clear: aspiring applicants to Harvard under the new alternative exam were to have prepared these experiments. The list contained forty experiments, each already described by other authors, and each expected to take “one to two hours in addition to the time spent in explanation” (Harvard, 1886, p. 1). An emphasis was put on taking a quantitative approach to these investigations, as the results of each were to be “exhibited numerically, graphically, or in tabular form” and recorded in the student note-books which were to be presented at the time of examination (Ibid., p. 1). As students were expected not only to have completed the required forty experiments, but also to have “a knowledge” of “all the physical principles involved” it was recommended that “one or two lectures” be given by instructors “each week throughout the year” (Ibid., p. 1). This set up the general course outline: a yearlong course with a combination of lab and lecture taking up three to five hours each week. The difference between this expectation in 1886 and that of Quackenbos in 1860 for whom laboratory apparatus was optional cannot be over emphasized. Here one sees the revolution of the laboratory method in full effect.

As mentioned previously, the experiments listed were not new; they had been previously described by at least one of four authors who espoused an experimental approach in the emerging tradition of *Physics*. These authors (Trowbridge, Pickering, Worthington and Gage) and their textbooks were not only mentioned in the Harvard leaflet but directly referenced as a source for the experiments listed below. “T” referred to Trowbridge’s *New Physics* (1884), “P” to Pickering’s *Physical Manipulation* (1883), “W” to Worthington’s *Physical Laboratory Practice* (1886) and “G” to Gage’s *Elements of Physics* (1884). These authors needed to be explicitly referenced, as there was still and “absence of any manual describing all the experiments” but this was being addressed and the reader was promised that “A pamphlet containing full particulars of the experiments” would be “prepared during the current year” (Harvard, 1886, p. 1). In the meantime, to eliminate the need to reference four different textbooks, the required experiments could also be completed with specifically stated substitutes from either Trowbridge or Worthington.

LIST OF EXPERIMENTS. — SELECTED FROM DIFFERENT AUTHORS.

	T.	P.	W.	G.
Volume.				
1. Direct Measurement of Volume, — [Density],	4–5, 8		42–45 50	
2. Displacement,	5	I. 22	47	
Density.				
3. Principle of Archimedes,	8	I. 89	64–66	80–82
4. Density of Solid by Flotation,			69–70 71	83
5. Densimetry,	10	I. 91	72	83
6. Density of air (rough),	22			[3]
Pressure.				
7. Estimation of Pressure at different depths,	25			47–49
8. Comparison of Densities, — Method of balancing columns,	29–30		62	
9. Mariotte's Tube, — [Estimation of atmospheric pressure by law of Boyle and Mariotte],				
10. Construction and Use of Barometer,	34	I. 108 I. 114	79 77	57 59 48–49
Mechanics.				
11. Elasticity, — Stretching of Wire, — [Relation of Stress to Strain, — Flexure],	48–50	I. 75	[127–149]	
12. Breaking Strength of fine wires,		I. 72		
13. Coefficient of Friction, — [Work],	89	I. 70	110–114	
14. Bent Lever, — [Comparison of masses], — Moments of forces,	[75–77]	I. 63	[85–99]	135–137
15. Centre of Gravity,	74–75	I. 66	100–109	96
Dynamics.				
16. Law of Falling Bodies,	66	I. 84		108–111
17. Velocity of Falling Bodies,	86–87			
18. Laws of Pendulum, — Influence of length of arc, — Variation of length of pendulum,	70 84	 I. 85	 151, &c.	104, &c. 110–111
Sound.				
19. Pitch,	283–284	I. 122		298
20. Comparison of two Tuning-Forks, — Graphical Method,	270	I. 125		
21. Resonance Tube, — Wave Lengths,	282–283			
22. Velocity of Sound,	291			
Heat.				
23. Temperature, — Fixed Points of Thermometer, — Melting and Boiling Points,	186		160–162	152
24. Expansion by Heat, — Air thermometer,	35 188–189	II. 94	173–176	170
25. Mixing hot and cold Water,	194	II. 95	177–179	170–171
26. Specific Heat, — Method of mixture,	197–198	II. 96	185	
27. Latent Heat of Water,	199–200	II. 97	187–191	
38. Latent Heat of Steam,		II. 83	157	142–143
29. Conduction of Heat,	[189]	II. 88–97	163–167	
20. Loss of Heat by Convection and Radiation, — Law of Cooling,				
Light.				
31. Photometry,	309–310 311	I. 132– I. 135		333–334
32. Law of Reflection, — Angle of Prism,	318, &c.	I. 140 I. 141, &c.		
33. Refraction, — Principle of Spectroscope, — Angle of Deviation,	317	I. 148, &c.		
34. Principal Focus of Lenses, — [Practical examination of telescope and microscope],	321	[I. 155]		
Electricity and Magnetism.				
35. Tracing-lines of Magnetic Force, — Electromagnet,	153	II. 65	228–230	
36. Dipping Needle,	130	II. 157		
37. Electrical Attractions and Repulsions, — [Arrangement of series in electro-positive order],			250–251	237, &c.
38. Distribution of Electrical Charge, — Proof Plane, — [Absence of charge in the interior of a conductor],			251–263	
39. Comparison of E. M. F. by Ohm's Law,	242, &c,		295–297	
40. Comparison of Resistances by Ohm's Law,	216–218		[295]	

Figure 18. The Forty Experiments from The Harvard List, (Harvard, 1886).

“The Attitude of An Investigator” (Harvard, 1887)

The promised pamphlet was indeed produced and published by Harvard in 1887. It contained not only descriptions of the experiments, but also a brief introduction which provided instructors with some guidance for building a course around them. First the object of such a course was stated as having three aims:

> 1st, to train the young student mentally and physically by means of tangible problems requiring him to observe accurately, to attend strictly, and to think clearly; 2d, to indicate strongly the methods by which physical facts and laws are discovered; 3d, to give practical acquaintance with a considerable number of these facts and laws, with a view to their utility in the thought and action of educated men (Harvard, 1887, p. 3).

The new list had been reduced to twenty-nine experiments, with most of the changes coming from the first half of the list. The revised list contained seven experiments in mechanics, eight in heat, three in sound, five in light, and six in magnetism and electrical currents. It was hinted that the reduction of the list was due to the “expense of time and money” (Ibid., p. 4). While the experiments of this reduced list necessitated students to make measurements, Edwin Hall thought additional experiments “of a less rigorous character” would needed to make them “intelligible and profitable” (Ibid., p. 4). Such simpler experiments could be found in the textbooks of Avery, Gage, and various other authors while those of the list ought to be supplemented with descriptions and explanations found in Trowbridge and Worthington. This indicates that Hall held the latter two to be of a higher caliber than that of Avery and Gage.

The course outlines were also made clearer. An appropriate course of preparation would occupy “five school-hours a week” for a full school year. It was expected that the experiments listed would take up “not more than half” of that time, with the remained spent on “explanations, supplementary experiments, applications, problems, etc.” for which work “a textbook of the ordinary sort” should be used by students. Textbooks would not be ditched, but they would function to help students properly comprehend their laboratory work. Hall held that completely abandoning a textbook would be beyond most teachers unless they were “extremely proficient” and had “an amount of time much greater than most” (Ibid., p. 5). This was one of the defining traits of the newly emerging tradition of Physics; laboratory work by students became the central focus with book study pushed to the periphery.

Another defining trait of the emerging tradition had to do with the relationship between students and scientific knowledge. Hall held that to ensure the aims of the course were attained students should as “far as practical” be kept in, “the attitude of an investigator seeking for things unforetold” (Ibid., p. 5). This did not mean keeping students completely in the dark but being allowed to complete the experiments to a level of accuracy determined by the apparatus and to draw their own inferences. The “main value of the student’s inferences” were to “enable him to understand, and without undue stretch of faith to accept, the established conclusions of physicists, and these conclusions should *in the end* always be made known to him” (Ibid., p. 5). This was entirely a different orientation towards the content being taught from that espoused by the tradition of *Natural Philosophy.* Physics sought to teach students not only the main principles of science, but also how scientists worked and came to add to the body of knowledge. Advocates of this tradition, such as Professor Hall, wanted students to approach the topic as young scientists, investigating rather than receiving new knowledge.

The pamphlet also gave some guidance regarding student notebooks, as these would need to be handed over as part of the entrance examination. Students were expected "to cultivate the habit" of not having to rewrite their notebooks; this required that they knew the salient points of the experiment before they began and focused their notetaking on "the main *evanescent* data" especially "numerical data of importance" (Ibid., p. 5). In describing the experiment, the student should focus on "telling wherein he has departed from the printed directions" and "the peculiar and significant details" that would most benefit the student in repeating the same experiment (Ibid., p. 5). Such advice had been given to my own students now, over a hundred years later demonstrating the lasting impact of the tradition developed in the 1880s. It is still desirable to have students take the role of active investigator, knowing their experimental tasks before arriving to class, taking careful notes especially regarding the data obtained, and able to discern where they departed from the instructions and take such notes as to allow them to perform the experiment with greater accuracy and reliability.

"Improved and Made More Uniform" (NEA, 1887)

In 1885 the NEA had appointed a committee to examine "how Physics-Teaching in our schools may be improved and made more uniform throughout the country", and in 1887 the committee published their findings (NEA 1887, p. 41). The committee consisted of well-known figures in the physical science education circle: Charles K. Wead, LeRoy C. Cooley, W. LeC. Stevens, W.F. Bradbury, and James H. Baker. Baker and Bradbury were both heads of schools, while Wead, Cooley and Stevens represented colleges. The five men had agreed "with gratifying unanimity" to certain general principles summarizing "the world's experience" when it came to physics teaching (Ibid., p. 41). While there was "nothing new" in these general principles, the

Association felt a need to exert its "influence or authority" over the "thousands of teachers" whom these principles needed to be "impressed upon" (Ibid., p. 41). The committee obviously held great faith in the NEAs ability to create educational change.

Before the committee presented the general principles as resolutions, they felt the need to clarify certain points of view. First, their recommendations were aimed only at "public schools" as found in "our cities and larger villages" and second, the details of the work ought to be left out until the general principles were recognized and accepted (NEA 1887, p. 41). Third, the main challenge lay in introducing physics in the primary and grammar grades, where it so far had not been introduced. The difficulty would be "the unpreparedness of teachers" who at this level had not been tasked with teaching physics previously (NEA 1887, p. 41). The "great danger" was that such teachers might turn the work into "the study of and recitation from a text-book" or else "she will give simple lectures," both methods being "radically wrong" (Ibid., p. 41). Instead, the committee recommended that teachers began by drawing out what the student had "already acquired" and then assist them "to re-arrange and classify it" (Ibid., p. 42). With a "few new facts" usually delivered "by experiment" students could arrive at a "common principle" the act of which trained their "reasoning powers" making the facts "more useful" in after life (Ibid., p. 42). The committee broke this general description down further, describing a complete learning cycle.

At the high school level, the work ought to be "mainly of the same character as before," namely taught by "the inductive method" (Ibid., p. 43). The main difference at the secondary level is that more time ought to be spent on "discovering principles and laws" and "to making deductions from them" (Ibid., p. 43). While the inductive method ought to be the primary focus at the secondary level, this was not to be taken to "the absurd extreme" in which textbooks were wholly abandoned. Indeed, students could "profitably use a text-book during a considerable part of the course" to supplement and guide what they learned during their investigations (Ibid., p. 43). The authors of the report believed that "the teaching of physics" would tend to improve if "all teachers" would agree to a "list of subjects" which should be "fundamental" and "taught by experiment" (Ibid., p. 43). To this end, the committee proposed such a list of forty-seven topics arranged in five areas: mechanics, heat, magnetism and electricity, sound and light.

The Committee presented four resolutions. The first identified the "peculiar mental training" physics was able to provide as the primary reason for teaching it, even above the "facts of physics" which were "of the highest interest and importance" (Ibid., p. 43). The second resolution regarded the amount of time for physics instruction, namely one hour per week in the primary schools, one to two hours per week in the grammar school, and five hours a week for a full year in the high schools. The third resolution was that teaching ought to be "inductive in spirit rather than dogmatic" with little time spent on "facts, principles, and deductions" unless able to be learned through observation or experiment; instead at the younger years students ought to study instruments and industrial applications (Ibid., p. 43). The fourth resolution was making some physics a requirement for college admission in order to improve the quality of work in both high school and college, as well as benefiting to the student. This requirement was to take effect in 1891 in time for the 1891-1892 school year.

"Nearly Everywhere Admitted" (AAAS, 1888)

At the meeting in 1884, the AAAS appointed four members to report on the subject of physics teaching. These four were T.C. Mendenhall, Wm. A. Anthony, H. S. Carhart and F. H. Smith. The AAAS report marked a conservative rebuttal to the work of Wead and the NEA. The report of this committee was long delayed, not being given until 1888 and republished in 1889.

The first section of their report explained the delay; learning of the appointment in 1885 by the NEA of a committee on the same topic (whose report is discussed above) Chairman Mendenhall sought to collaborate with Chairman Wead. Given “the wide geographical distribution of the members” the efforts to secure a joint meeting failed however (AAAS, 1888, p. 29). Most members of the AAAS committee did attend the NEA’s annual meeting in 1886 at Buffalo, and the following year in Washington, D.C the AAAS committee convened again to discuss the matter and write their report. Two immediate conclusions were forthcoming: it was no longer thought “necessary or desirable” to insist upon the importance of teaching physics in America’s schools, and that “nearly everything which can be justly claimed in now nearly everywhere admitted” (Ibid., p. 29). Thus, at least the ideal of physics education had been established, even if there remained much work to be done in achieving that ideal.

The remaining conclusions however were rather surprising. The AAAS Committee on Physics-Teaching had largely divergent recommendations to that of the NEA. The American Association was far more conservative in what it thought best. In particular, they scaled back considerably on the rush to change to inquiry-based science education. Regarding whether or not physics ought to be taught at all in the grammar school, the AAAS felt “nearly everything depends on the teacher” for only “an extremely small percentage” of teachers had a good chance of teaching the subject well. The “prevailing custom” of requiring all teachers of a certain grade to teach physics was “greatly to be regretted” (Ibid., p. 30). It would “prove disastrous to the best interests of science” to force the introduction of physics into the grammar schools, rather it was better to wait as the “rapid advancement” of “real scholarship” would soon result in more teachers “competent to teach physics” (Ibid., p. 31). Where physics was taught in the grammar schools, much ought to be left to the discretion of the teacher.

When it came to physics instruction at the high school level, the AAAS committee began with the qualification that the high schools were the "final scholastic training" of the "large majority" of young people. This meant that any provisions made for those attending college or university must be "merely incidental" (Ibid., p. 31). By the end of the course, students ought to "be able himself to plan and carry out an attack upon some of the simpler problems of the science", (Ibid., p. 31) meaning they ought to be able to plan and conduct their own laboratory investigations. However, before getting into the lab students should first spend "two terms" doing "text-book work" for three hours a week enlivened by "illustrative experiments performed by the instructor" (Ibid., p. 32). Simple laboratory exercises ought to be introduced only during "the last term" of the year. This laboratory practice ought to focus on "a careful and more exhaustive study of a few problems" solved with "the highest degree of accuracy attainable" (Ibid., p. 32). This would require scarcely more than one hundred hours of physics; however, the committee recommended the course be extended to two years, allowing the equivalent of five hours per week.

There followed a barbed attack upon the proponents of beginning with lab work. It was well known "that many teachers of physics, and many more who are not teachers of physics, insist on the introduction of laboratory practice from the beginning, some even going so far as to claim that the use of the text-book may be entirely dispensed with" (Ibid., p. 33). Such a notion was "one of those mistakes in which pedagogics" were "caught on the rebound from other and generally more serious errors" (Ibid., p. 33). Even at the college level, where physics was "necessary and essential" to a "liberal education" the minimum course ought to "consist entirely of text-book and recitation work" (Ibid., p. 33). The AAAS committee clearly held that the rush to adopt more lab work at the expense of recitations and textbook work which emphasized the rote learning of basic principles had gone too far, and needed to be reined in. Indeed, their final recommendation was that "whenever the Association speaks" it should do so "governed by a wise conservatism" (Ibid., p. 34). Unsurprisingly several years later one of the committee members, Henry Carhart, wrote a physics textbook for high schools, in collaboration with Horatio Chute would had already written a laboratory manual, which emphasizing the need for order and clarity. The collaboration of Carhart and Chute would continue for several decades and proved to be an alternative to the textbooks by Alfred Gage, emphasizing a more restrained deductive approach in contrast to Gage's inductive approach.

"A Somewhat More Elementary Work" (Gage, 1888)

In 1887 a new textbook by Alfred Gage was entered into the Library of Congress. Entitled *Introduction to Physical Science,* this second work differed from the first in making "the same methods available in a somewhat more elementary work," with the intention to bring it within the "easy comprehension of the ordinary pupil" at "the average high school" (Ibid., p. iv). While the *Elements* had been popular because of its reliance on simple inquiries and student induction, the quote suggests that its approach had been too high for many students at a variety of schools. The new book was published in 1888 and in it Gage celebrated the "successful adoption of laboratory practice in all parts of the United States and the Canadas" in the years between his first and second textbook (Gage, 1888, p. iii). In his own estimation the practices of teaching physics were changing. Gage promised his reader that using his system, "Any teacher will find his labors lighter than under the old elaborate lecture system; and he *will never have occasion to complain of a lack of interest on the part of his pupils* [original italics] (Ibid., p. iv).

Such bold promises fueled fire driving the adoption of lab-based physics and the consumption of Gage's textbooks.

In this new textbook, Alfred still referred to his scheme as "the inductive plan" yet Gage had already changed his mind about a few things. While clear enough in his earlier text that laboratory investigations were to precede didactic instruction, in this later text he wrote, "As a rule, the principles and laws are discussed in the classroom in preparation for subsequent work in the laboratory. The pupil then enters the laboratory…" (Gage, 1888, p. iii). One can assume the reason for this change was born out of the experience of "about six years in requiring individual laboratory work from my pupils" although Gage gives no reason himself for this about face (Ibid., iii). Perhaps it simply proved too challenging for students to dive into lab work without being first given a sense of context regarding what they were exploring.

The comment regarding his acquired years of experience also reveal how little he had with individual student lab work when publishing his first textbook, the *Elements.* Given the admission of "about six years" experience of requiring labs, Alfred must have just used the system he propounded in his *Elements* for a year or two at most. Since his *Introduction* was entered to the Librarian of Congress in 1887, six years earlier would be 1881; allowing an extra year for the "or so" one can surmise he began requiring labs either in the school year of 1880-1881 or 1879-1880. This afforded only a year or two of experience concurrent with the writing of his first textbook, and presumably experience had taught him the need to temper the laboratory work with some preliminary instruction.

In terms of continuity, Gage kept his notion of students rotating around set lab stations. Alfred provided a clear description of what instruction should look like in his class or those following his approach.

> The pupil then enters the laboratory without a text-book, receives his note-book from the teacher, goes at once to any unoccupied (numbered) desk containing apparatus, reads on a mural blackboard the questions to be answered, the directions for the work to be done with the apparatus, measurements to be made, etc. Having performed the necessary manipulations and made his observations, he surrenders the apparatus to another who may be ready to use it, and next occupies himself in writing up the results of his experiments in his note-book (Ibid., p. iv).

Students were assessed according to their notebooks, which contained "the only written tests to which the pupil is subjected" with the exception of the annual exam by the Board of Supervisors. Since laboratory work under Gage was seen as a test, students were not to talk to one another, but only to the instructor.

"The Laboratory Method" (Chute, 1889)

Horatio Nelson Chute began this "guide for the physical laboratory" rather simply, "This book has been written with the object of promoting the teaching of Physics by what is known as the Laboratory Method" (Chute, 1889, p. iii). This simplicity belies the significance of his word choice. Here we find the term "laboratory method" to describe the new pedagogical trend. Furthermore, Chute acknowledges that his purpose has been to promote the method first and foremost; the teaching and engagement of students was to follow. Three years later, in 1892, Horatio Chute would collaborate with Henry Smith Carhart to write a textbook beginning a series which would span three decades from before the *Report of the Committee of Ten* (1893) until after the *Cardinal Principles* (1918). Their collaborative work traced a clear trajectory through the period of interest in this dissertation, a trajectory mirrored in the changing titles of their books. Carhart we have already met previously as a member of the AAAS committee on physics teaching. Here we find Chute as the sole author of a lab manual that competed with the work of Alfred Gage. Horatio Chute's *Elementary Practical Physics* was published in 1889. While Gage was working out of Boston, Chute taught at the Ann Arbor High School (today's Pioneer High School) in Michigan.

While Gage spent his most polemic prose portraying the need for students conducting their own investigations, Chute spent his arguing that, "instruction should, in the opinion of the author, precede the introduction of the student to the laboratory" (Ibid., p. iii). Gage himself had come around on this point, as seen in the preface to his *Introduction to Physical Science,* published but a year earlier. For Horatio however, it was an important point which consumed a full page and a half of his Preface. Chute felt it was only by having "class instruction" "precede the student's study of that subject experimentally" would the student recognize "the complete significance of the experiment" with "intelligent work secured" while excluding "that which is lifeless and mechanical" (Ibid., p. iv). The distinction between Gage's original stance and that of Chute on whether to first investigate or first instruct marked a real philosophical difference in their approach to laboratory work.

Both set out with the intention to deepen and enrich the teaching a physics through laboratory investigations, helping students to "break through a wall" of "abstract definitions" (Gage, 1882, p. vii) by excluding "that which is lifeless and mechanical" (Chute, 1889, p. iv). But they differed in just how the lab would achieve these goals. Gage saw the laboratory as a place in which students could "interrogate Nature with his own hands" allowing students to catch "something of the spirit which animates and encourages" working scientists (Gage, 1882, p iii).

The lab for Gage in 1882 was a place of figuring out, a place to discover physical phenomenon unburdened by theory.

For Horatio, "The office of the school physical laboratory is not one of original discovery" but rather its first purpose was to "put the student in the best possible position to see what he looks at, in order that fact-knowledge may be added to word- knowledge in the most impressive way by having the head and hand work and learn together" (Chute, 1889, p. iv). Laboratory work was intended first to help students by allowing them to manually manipulate equipment and secondly to "to train the faculties to exactness of observation, independence and carefulness in forming conclusions, and good judgment in weighing evidence" (Ibid., p. iv). The human race, as Chute saw it, had been developing its scientific knowledge over the course of centuries; why then should students be expected to attain the same heights within a year unless aided in their comprehension. For Horatio Chute the notion that, "the Laboratory Method requires a student to discover for himself the important laws and truths of the physical world" was "a mistaken supposition" which "unfortunately" prevailed among science teachers (Ibid., p. iv). One is left to wonder if this was directly aimed at Alfred Gage or not.

Rather diplomatically, Chute conceded that use of his textbook was not restricted "to any particular theory of practical science teaching" (Ibid., p. ix). He allowed that,

> If you believe that a full course of didactic instruction should precede the admission of students into the laboratory, and that the practical work should be entirely quantitative, then omit the qualitative and select from the quantitative such as is adapted to your wants (Ibid., p. ix).

Chute warned however that in doing so, it became "nearly impossible" for a student "to accomplish much" since all the practical work was then done in "a small part of the school year" (Ibid., p. ix). Much better to start the lab work a week or two after the classroom work had begun and then carry on the two simultaneously. This kept the "didactic instruction" far enough ahead of the investigations to allow the student to work intelligently. Chute also rather graciously admitted that if one held the same view as "many of our ablest teachers" namely that the laboratory work should precede that of the classroom then his text contained a complete collection of experiments to choose from. What was more, in such a case, the "labor of supervision" in such a case was much reduced by the hints included on observations, recording of data and its correct interpretation (Ibid., p. x). Another point of contention was regarding the whether or not students ought to work all on the same experiments at the same time. As Chute describes,

> There are in use two methods of conducting laboratory work, known as the *separate system* and the *collective system*. Under the former each section of two students would work on different problems, the apparatus going around in rotation… The collective system is the ideal one. Under it all are engaged on the same work at the same time (Chute, 1889, p. xiii).

The advantage of the separate system was in reducing the need to have multiple sets of the same equipment. However, it made it impossible for students to follow experiments in a logical order. The collective system allowed a teacher the opportunity to better match their instruction with the work in the laboratory, giving the needed instruction just ahead of the experimental work. Chute, eminently practical, recommended some combination of the two depending on the availability of equipment.

Comparing the NEA and AAAS reports:

The two professional bodies, one of educators (the NEA) and the other of scientists (the AAAS), while agreeing to the importance of physics and the need to improve the quality of its teaching, differed in their views of how the field should move forward. The National Educational Association promoted the inductive method which centered on inquiry-based investigations by students, while the American Association for the Advancement of Science, sought a more measured, traditional approach emphasizing mastery of content over process. Advocated of either approach could be found in the new textbooks which had been produced since the decade began. Both held the teaching of physics to be important but differed widely in their recommendations; inductive vs deductive; use of textbooks; discovery or not. Clearly, the discussions and debates around how best to teach physics had only begun and would continue to gather steam and accelerate into the next millennium.

It is interesting to compare the reports of the two committees in their use of gender (that of the NEA and the AAAS) in their discussion of grammar school physics instruction. The AAAS in recommending that the grammar school teacher be allowed freedom in choosing the sequence of topics, claimed the teacher should be guided by "his own taste and predilection" (Ibid., p. 31). The NEA on the other hand, in discussing the perils of the unprepared grammar school teacher, rather patronizingly held that "she finds little detailed help in print of the kind she wants" which place the teacher "in great danger of making the work consist in the study of and recitation from a text-book, or else she will give simple lectures to her pupils" (NEA, 1887, p.

41). In that sentence alone, there are four uses of female pronouns. To be clear, both the NEA and the AAAS reported on the danger of bad physics teaching in the grammar schools, but the AAAS held that male teachers could do well enough if given the freedom to do so, while the NEA held that women needed strong guidance to avoid the same pitfalls.

Section summary

The 1880s saw the emergence of *physics* as a new instructional ideal, with student laboratory work as its core distinction. The second half of the decade witnessed Harvard implementing a new experiment-based physics examination for students seeking admission. As a leading University, this move set a standard which other Universities followed and created new incentives for preparatory schools to adopt the laboratory method. The topic of how high school physics was best taught continued to hold the attention of two large professional associations, the American Association for the Advancement of Science and the National Education Association, which published their opinions and recommendations in a series of reports. Alfred Gage (1888) published a second textbook based on the laboratory method, aimed at students for whom his earlier work was too challenging. Horatio Chute brought out a manual designed specifically for the high school physics laboratory to guide students in their investigations. In the following section, we see the new ideal come to maturation as an academic tradition.

Maturation (1890-1900)

In this section, we see physics mature as a new instructional tradition. Carried away with an over emphasis on inductive discovery early on, supporters of the new tradition begin to advocate for balancing pedagogical methods and a consensus begins to form around what *physics* in American high schools ought to look like. It begins with examining a paper read to the Associated Academic Principals of the State of New York in 1890, after which the first textbook by Edwin Hall and Joseph Bergen (1891) is examined, a text written to support a course aimed at the requirements of the Harvard entrance exam adopted in 1886. The textbooks by Hall, who also wrote much of the entrance exam, were taken as the benchmark for college preparatory schools. Following this the first combined effort by Carhart and Chute is looked at, a work which resulted in a collaboration spanning several decades. The *Report of the Committee of Ten* (1893) is then reviewed, a *Report* about which much has been written and which is often hailed as marking the triumph of the laboratory method's acceptance. The section finishes by looking at new works by previously examined authors, allowing one to witness the extent of change in little more than a decade.

"Making A Mixture of The Methods" (Arey, 1890)

Albert L. Arey (1890) published his thoughts on *Methods of Teaching Physics* after reading them to the Associated Academic Principals of the State of New York. By 1890 the time had passed, in his opinion, when the importance of physics needed to be discussed, the time had come to discuss how it was best taught. From his perspective there was "no subject which offers a greater variety of methods than physics", of which he enumerated three: the "pure lecture" method, the "pure cram" and the "all laboratory practice" (Ibid., p. 37). He discussed each in turn. The lecture system Arey found, "is not the best, since it relieves the pupil of all mental exertion", while the text-book method depending on the teacher could either "do little" or "do much," but most surprisingly he found the laboratory method "in its extreme form" to be "the poorest method" (Ibid., p. 37. Arey acknowledged that "many teachers will class my remarks as heresy" but students taught with a pure laboratory approach he found to be "weak in theory" with only a "fragmentary knowledge of facts" (Ibid., p. 37). He then quoted a passage from the AAAS report of 1888 to lend credence to his remarks.

As Arey saw it, "The solution of our problem I believe lies in making a mixture of the methods. Let us use the lecture where it is found serviceable, the didactic method supplemented by laboratory work being our main dependence" (Ibid., p. 38). Arey distinguished between quantitative experiments which yielded "very much better results when performed by the pupil, compelling clear thinking, and requiring careful manipulation" while qualitative experiments, or "illustrative" experiments which were better done by teachers, again quoting the AAAS report of 1888. Arey was not above taking a shot at Alfred Gage as dealing "almost exclusively with illustrative experiments" (Ibid., p. 39). This analysis led Arey to a set of recommendations.

> 1st. A sufficient amount of text-book work should be done, to give the pupil a foundation in each of the grand divisions of the science.
>
> 2nd. This text-book work should be illustrated by experiments performed by the teacher.
>
> 3rd. All the time that can be allotted to laboratory work should be expended upon quantitative experiments.

Arey continued with more concrete advice to the assembled principals about how he conducted his laboratory. First class sizes above 25 students could "not be handled successfully by one person" even with the use of student assistants; he had tried it (Ibid., p. 40). He had also tried two plans for the work, one in which a given day of the week was set aside for laboratory work and another in which the topic was first covered completely in class and then what time remained was spent experimenting upon it. Arey recommended the second, as fewer instruments were needed as students could work on different experiments simultaneously before switching when finished. Students would work in pairs, and the laboratory experiments would be assigned well in advance, so students were prepared with prior discussion, explanations and special instructions. Laboratory apparatus would already be set up at each table ready to be used so student time was "economized" (Ibid., p. 41). In this Arey followed Pickering's suggestions from 1873. Pickering had developed this system with his students at MIT and Arey's application to the secondary level showed the downhill flow of ideas.

"A Backbone of Quantitative Work" (Hall & Bergen, 1891)

In 1891, Edwin Herbert Hall and Joseph Young Bergen produced *A Textbook of Physics, Largely Experimental, on the basis of the Harvard College "Descriptive List of Elementary Physical Experiments."* According to Hall and Bergen, the need for a new textbook was grounded in the results of the new admission test at Harvard, beginning in 1886. The new exam required candidates to perform laboratory experiments in person at the University. These laboratory-based exams made it "evident" that the general "inexperience of teachers" in teaching experimental physics required a new "special course of experiments" (Hall & Bergen, 1891, p. iii). Professor Hall ran the entrance exam in physics at Harvard and had authored an accompanying pamphlet known as the Descriptive List detailing the experiments expected of candidates. He was well positioned then to author the textbook for such a special course and so make himself an authority on the topic of high school physics. Junior Master Bergen who worked at the English High School in Boston lent the credibility of actual high school teaching experience to the textbook. Hall & Bergen, in leveraging Hall's authority and straddling the school-college divide, produced one of the most used textbooks during the period, running through multiple editions over several decades.

In the introduction, Hall and Bergen clarify the connection between their textbook and the Harvard entrance exam. As the subtitle of their textbook made clear (*On the Harvard College Descriptive List of Elementary Physical Experiments*) the purpose of Hall and Bergen's new textbook was to support the new Harvard admission test. It was the success of the new courses based on this list that created the need for Hall and Bergen's text. The story begins with a "very important change" by Harvard College to require candidates to be examined in laboratory work rather than text-book work in physics (Hall and Bergen, 1891, p. iii). The old exam, much enlarged, was retained for those coming from schools without sufficient laboratory facilities. It was, according to Hall and Bergen, this new entrance exam which necessitated the creation of "a special course of experiments" due to the "inexperience of teachers and the very different standards and methods likely to be adopted by them" (Ibid., p. iii). The results of the first year's exam showed students came with widely different levels of preparation. The special course that was called for was thus engendered from Harvard's desire to see more consistent results from its freshman candidates.

To help prepare such a special course, a circular was sent out to various preparatory schools in the same year of 1886. From this circular it was found that preparatory schools spent about five lecture hours a week on physics, with some additional hours each week on laboratory work. This became the standard expected for the entrance exam and the *Descriptive List of Experiments* that would be developed by Edwin Hall. The success of a new course designed to help prepare students for the exam depended greatly on the choice of experiments, and there were two criteria Hall and Bergen emphasized: rigor and relevance. Hall and Bergen found "a backbone of quantitative work" was crucial to prevent the course "from degenerating into mere perfunctory trifling with apparatus" (Ibid., p. iv). The experiments chosen also represented an attempt "to bring together such experiments as would have the most frequent and important applications in ordinary life" (Ibid., p. iv). In emphasizing quantitative work over qualitative discovery labs, Hall and Bergen distinguished their approach from that of Gage and Charles Wead's recommendations.

As the authors saw it, "None of the current text-books, excellent in their way as some of them are, meet fully the special needs of a class using the College pamphlet" (Ibid., p. iv). The authors' intentions were to guide the student "in his thinking, but not to relieve him from the necessity of thinking" (Ibid., p. v). Such student thought was cultivated by giving the formula for one experiment (on Specific Heat) but not for another, related experiment (Latent Heat) where students were expected to connect the two situations. In some instances, the explanation for a phenomenon studied in lab was not given right away, in order to allow students to draft their own conclusions first. While the book was expressly written to support the Harvard Admission process, it was also intended to support "the needs of high schools and academies in general," with both authors believing "the book will prove as useful to those who do not look forward to a College course as to those who do" (Ibid., p. v).

"The Laboratory Method Has Come In" (Carhart & Chute, 1892)

By 1892, the authors Carhart and Chute clearly felt the *laboratory method* had arrived, "During the past decade the teaching of Physics in high schools and universities has undergone radical revision. The time-honored recitation method has gone out and the laboratory method has come in" (Carhart and Chute, 1892, p. vii). Together Carhart and Chute established a winning formula as evidenced by the long running series of physics textbooks they authored (Carhart & Chute, 1892, 1897, 1901, 1905, 1907, 1912, 1917, 1920), establishing their credibility. They were well aware how far things had come in a very short while, "A few years ago it seemed necessary to urge upon teachers the adoption of laboratory methods to illustrate the textbook; in not a few instances it would now seem almost necessary to urge the use of a text-book to render intelligible the chaotic work of the laboratory" (Ibid., p. viii). It should not be believed that all American schools had adopted the laboratory method by this date and completely abandoned either the lecture or book method, but Carhart and Chute certainly felt enough had to warrant such a claim.

To be clear, what Carhart and Chute opposed was "the method of original discovery" rather than the inclusion of student laboratory work. They saw the whole-hearted embrace of the inductive approach as a backlash against the excessively authoritarian approach of *natural philosophy.*

> "As a natural reaction from the old *regime,* in which the teacher did everything, including the thinking, came the method of original discovery; the textbook was discarded, and the pupil was set to rediscovering the laws of physics. Time has shown the fallacy of such a method, and the successful teacher, while retaining all that is good in the new method, has already discovered the necessity of a clearly formulated, well digested statement of facts, a scientific confession of faith, in which the learner is to be thoroughly grounded before essaying to explore for himself." (Ibid., p. iii).

In the eyes of Carhart and Chute, the previous tradition of *natural philosophy* was equivalent to the old regime in pre-revolutionary France, the change in instructional strategy that accompanied the new tradition of physics was so distinctive.

Carhart and Chute had little love for the *natural philosophy* tradition, but also that the inductive methods espoused by Wead and others (1884) created laboratories in which students were “apt to discover little beyond his own ignorance” (Carhart and Chute, 1892, p. iii) as without previous instruction they came to the lab “without any ideas” of what they were to see, “entire ignorance of methods of experiment” and “without skill in manipulation” and thus set up for failure. For this reason, they held the student “should be kept in his class-work well ahead of the subjects forming the basis of his laboratory experiments” (Ibid., p. v) and wrote their textbook just “for the class-room” to provide students with the necessary background. In calling for a more balanced approach to instruction Carhart and Chute were in agreement with Arey who advocated “making a mixture of methods” (1890, p. 38). Indeed, Carhart had been a member of the AAAS committee in 1888 which wrote the report Arey cited in his speech to the Principals of New York.

Interestingly Carhart and Chute in the stated aims of their textbook echoed those of many writers under *natural philosophy*. They sought to “formulate clear statements of laws and principles”, to “illustrate them amply” and to “observe a logical order and sequence” (Ibid., p. iv). These were the same aims of many *natural philosophy* textbook authors. Perhaps this is not to be too surprising for what else can a textbook aim at, if its function is to lay a field of knowledge before a student? The significant difference then between authors of the *natural philosophy* tradition, and those of the *physics* tradition was the firm belief of the latter that students must *also* do laboratory work. This is the consensus opinion one finds coalescing in the specialized literature of the 1890s: students needed both to conduct laboratory investigations and receive lectures and readings, with the classroom work preceding the laboratory work.

"Half of The Time Devoted to Be Given to Laboratory Work" (NEA, 1893)

In the late fall of 1892, ten gentlemen met at Columbia College, in New York City. They had a singular purpose: to organize a national debate on, "The best methods of instruction, the most desirable allotment of time...and the best methods of testing" high school students (NEA, 1894, p. 3). At such a conference every "principal subject" taught in the secondary schools of the United States would be examined. As an attempt to align the efforts of secondary schools and colleges throughout the rising nation, a combination of teachers, principals, and college professors were being called to attend the conference. Selected by the National Council of Education, and meeting at the behest of the Directors of the National Educational Association, these ten individuals were regarded as "representatives of leading colleges and secondary schools in different parts of the country" (Ibid., p. 3). These men with their imposing titles came to be known in due time simply as *The Committee of Ten*. The work begun in New York, marked the first attempt to standardize the curriculum of secondary schools in the United States. A strong case for the importance of the *Report of the Committee of Ten* in its place and time was built by Theodore Sizer. Sizer (1964, p. xi) found the *Report* alternately referred to as "gospel," "the educational sensation of the New Year" (following its publication), "the embodiment of the most profound, practical, and democratic philosophy of education ever enunciated in America" (sixty years later) and even, "the most important educational document ever published in this country" by William T. Harris, US Commissioner of Education.

By 1893, the day of the laboratory method as the dominant means of teaching high school physics had arrived in America. At least the experts of National Educational Association felt it had. The publication of the *Report of Committee of Ten* can be seen as a vindication of science education and its importance compared with that of both the classics and the other modern subjects (such as English and History). The perceived importance of laboratory work as a vital component of science education can be seen in the various other recommendations of the physics committee. In their report of that year, the Committee of Ten recommended:

- "at least 200 hours be devoted to the study of Physics in the high school,"
- "that both Physics and Chemistry be required for admission to college,"
- "that at least one-half of the time devoted to [physics] be given to laboratory work,"
- "that laboratory work in Physics should be largely of a quantitative nature,"
- "that careful note-book records of the laboratory work in both Physics and Chemistry should be kept by the students at the time of the experiment,"
- "that the laboratory work should have the personal supervision of the teacher at the laboratory desk,"
- "that the laboratory record should form part of the test for admission to college, and that the examination for admission should be both experimental and either oral or written" (NEA 1893, p. 118).

The conference or sub-committee on Physics, Chemistry and Astronomy laid out the best practices regarding the teaching of physics, chemistry and astronomy, beginning with the study of phenomena and experimentation commencing in elementary school. The fact that 200 hours of physics were being recommended, with half of it in the laboratory, indicates that the new tradition of physics had taken root and begun to flourish, for the conference could only have asked for such a large number of hours of lab work if the practice of student labs were becoming somewhat commonplace at the high school level. Furthermore, the subcommittee recommended that, “There should be no difference in the treatment of Physics, Chemistry, and Astronomy, for those going to college or scientific school, and those going to neither” (Ibid., 118). This clearly indicates the subcommittee aimed at making laboratory experiences a central part of the high school experience of available to all students, and not only the college bound few. That such importance was placed on laboratory practice in these national recommendations marked a clear victory for those who sought official sanction for the laboratory method.

“An Essential Part of Every Science Course” (Gage, 1895)

Thirteen years after his *Elements of Physics* caused “much healthy discussion” (Stevens, 1895, p. 306), Alfred Gage brought out “a new work.” His stated reasons included “changes in the technical nomenclature” and the “many improvements in methods of presentation,” but “above all, the whole subject of Electricity and Magnetism has outgrown its former apparel” (Gage, 1895, p. iii). As a reviewer put it, this text reflected Gage’s “riper experience in adapting the expression of truth to the capacity of those for whom the book is intended” (Stevens, 1895, p. 307). What changed was Gage’s early insistence on thoroughly inductive methods. He no longer insisted that the experiment preceded the instruction, just as one did not “teach the student to swim before entering the water” (Gage, 1882, p. vii). Indeed, Gage saw the 1895 book as “simply a textbook” expecting that any teacher would supplement its teachings with “laboratory work” (Gage, 1895, p. v). Gage had published a separate laboratory manual just two years earlier. What remained consistent was Gage’s commitment to the importance of student investigations, “Education, in Physics, implies the presentation of the great truths of that science…and the furnishing the student an opportunity of observing and exercising the logical processes that have led to the discovery of those truths” [sic] (Ibid., p. iv). For this reason, “laboratory practice has come to be considered an essential part of every scientific course” (Ibid., p. v). Although Gage separated his text-books and laboratory manuals in the 1890s, his work can be seen as indicating just how mature the traditions of physics had become. Gage was tailoring his work to fit into the new norms, where he once had been the one to help break out of the old ones surrounding *natural philosophy*.

“Settling Down to A Golden Mean” (Avery 1895)

One can also see how thorough and complete the adoption of student laboratory work had become, by examining Elroy M. Avery’s *School Physics: A New Text-Book for High Schools and Academies* published in 1895. Two of Avery’s previous textbooks have been discussed; his *Elements of Natural Philosophy* (1878) and *First Principles of Natural Philosophy* (1884). The first of these was quintessentially true to the tradition of natural philosophy, emphasizing rote memorization with little to no mention of laboratory work. His *First Principles*, written only six years later but after the reports of Clarke (1880) and the AAAS (1881) and Alfred Gage’s popular 1882 textbook, sought to incorporate simple experiments. By 1895 Avery felt the need for an entirely new book, one built around student laboratory experiments and bearing *Physics* in the title. “For several years there has been a growing tendency in the high schools of the country to indulge in laboratory methods. An effort has been made to adapt this book to such needs” (Avery, 1895, p. 3). While “high school laboratory work has its limitations” Avery explained,

> It affords a needed variation from the old method in which the author stated facts *ex cathedra* to be accepted and memorized by the pupils, and from the less objectionable plan in which the teacher performed all the experiments and the pupil simply observed and admired (Ibid., p. 4).

Avery, once an author in the *natural philosophy* tradition very well captured its essence and short-comings. The limitations of laboratory work lay in "the capacity of the pupils, in the time at their disposal, in laboratory equipment, etc.". Avery clearly states that he has "no sympathy with the idea that the pupil should have set before him the impossible task of rediscovering all the physical truths known to modern science" (Ibid., p. 3). Avery felt that a "golden mean" had perhaps been achieved in which it was recognized that books, direct instruction, and laboratory work all had a role to play. In making such a statement he takes a stance similar to advocated by Arey (1890) just a few years earlier.

Avery goes on to provide practice advice to the teacher. The importance of laboratory work is made clear by such pronouncements as, "Each pupil is expected to perform as many of the laboratory exercises as possible" (Avery, 1895, p. 4). Likewise, the relationship of lab to lecture is clarified, "The classroom work must be kept ahead of the laboratory work; i.e., the pupil must come to the laboratory with some knowledge of the principles involved in the work that he is required to perform" (Ibid., p. 4). Such a recommendation can be contrasted with those of Rolfe and Gillet (1874) who in accordance with the earlier Oswego Movement advised that each lesson be begun with some simple experiment which could then be explained by the teacher and finally read about. The purpose of laboratory work in Avery's 1895 conception was as a place for students to cultivate "habits of accuracy of observation", "systematic methods", and “an ability to reason from observed particulars to general laws” (Ibid., p, 5). Avery preferred rather smaller classes of ten or twelve, small enough “that the teacher may get to each pupil at short intervals to check gross errors at the beginning, and thus prevent much waste of time”. Avery admits that so much laboratory work, together with the work of “enforcement; questions, discussions, supplementary experiments, and problems” took up a great deal of time and asked that school authorities keep that it mind.

Section Summary

By the 1890s it becomes easy to recognizes the same fundamental outlines of a physics course as taught today. Textbooks were written by those specializing in physics and often by the collaboration of a secondary teacher and a professor (Carhart and Chute, 1892; Hall and Bergen, 1891). This allowed the authors to combine their experience and expertise in what was becoming a more competitive market, with the professor providing the recognized academic authority and the teacher providing the needed classroom perspective. Chapters or units covered the standard topics still emphasized for another hundred years: mechanics, heat, magnetism and electricity, sound and light. Much time was devoted to quantitative laboratory work, with students working singly or in pair, and making careful notes in dedicated notebooks. This was seen as being crucial to developing the skills necessary to do advanced work in physics. Physics was seen as an exemplary means of teaching mental discipline, accurate observation, and rigorous concentration. However, in the following decade it would also come to be seen as too narrow and rigid, which prompted the emergence of another reform effort, one calling itself *The New Movement* (Olesko, 1995; Rudolph & Meshoulam, 2014; Meltzer & Otero, 2015).

Chapter Summary

This chapter has discussed the results of studying a selection of the physical science textbooks available in the United States during the 19th century. It first maps out the tradition of natural philosophy in American classrooms, an instructional tradition which dominated the period from before 1833 until at least 1879 as the main means by which physical science was taught. The chapter then examines some early efforts in the 1870s to move away from this earlier book-bound tradition, before moving on to look at the efforts in the 1880s which began a lasting shift towards student laboratory work in the third section. This third section, entitled *Emergence* is in many ways the heart of this dissertation, as one sees the laboratory method emerge as the favored method of instruction as physics began to displace natural philosophy. The fourth section of the chapter, entitled *Growth* and covering the period of 1886 to 1889, sees this new tradition of physics gaining ground as more textbooks were written in the new style and some colleges began changing their admission requirements. The last section, entitled *Maturation* and covering the last decade of the 19th century, looks at how the new tradition of physics evolved as it gained wide-spread acceptance.

The first section, *The Tradition of Natural Philosophy*, focused on early textbooks which help define the instructional tradition which preceded physics. Until the 1880s, nearly all textbooks written for high school physical science belonged to this tradition. The following examples were discussed: Olmsted, 1833; Parker, 1844; Quackenbos, 1860; Norton, 1870; Peck, 1871; Steele, 1871. These textbooks shared traits which exemplified the natural philosophy tradition, namely: a didactic approach which emphasized definitions and classifications of key terms, a focus on illustrations as a means to minimize the need for experimentation, and an organizational structure to support student recitations of memorized content. Textbooks of this tradition flourished as the sciences gained popularity for they were easy to use. Teachers of the period often lacked specialized content knowledge and only had access to a minimum amount of laboratory equipment, if any at all (most of which would have been too delicate and expensive for student use). By substituting illustrations in the place of actual experiments, offering clear definitions and explanations, and providing teachers with easily accessible questions with which to assess students, these textbooks dominated the market until the 1880s.

The second section, *Early Stirring*, looks at some early efforts to shift away from purely didactic, book-based learning. These efforts included those of Cooley (1872), Pickering (1873) and Rolfe and Gillet (1874). Cooley's work was aimed more at the elementary level than the high school but sought to shift instruction to focus on simple demonstrations and experiments using what was known as the object method. Rolfe and Gillet similarly drew upon the practices of the Oswego Movement and promoted an instructional cycle with began with a demonstration to establish visually, or experientially, what was to be studied. After such an enlivening demonstration, students were to master the content through book study and lectures. While this did not yet amount to a laboratory-based approach to teaching, it moved in that direction. The work of Pickering was very advanced, and not easily adaptable for the high school level, as its author led the way in developing the laboratory method of instruction at the university level while teaching at the Massachusetts Institute of Technology. These early examples showed the cracks beginning to appear in the natural philosophy tradition as a growing sense of dissatisfaction with such a book-based approach to science mounted.

The third section of this chapter, *Emergence*, examined the textbooks by Gage (1882), Avery (1884), Trowbridge (1884) and Worthington (1886) which answered the call for a laboratory-based approach to teaching the physical sciences. These books were written, at least partially, in response to the reports by Clarke (1880), AAAS (1881), and Wead (1884) which criticized the way in which physical science was being taught. The interplay of these textbooks and reports is especially clear in the case of Gage's (1882) work in which he draws upon some of the exact same arguments and metaphors as to why a new approach was warranted as Clarke (1880) had given in his report; the textbook by Gage is then singled out by Wead (1884) as the best example of how physics ought to be taught. The new textbooks of the physics tradition covered the same core content as natural philosophy had: motion, heat, acoustics, optics, and electricity and magnetism. The difference was in their approach, which emphasized student experimentation as critical to students gaining a really understanding of the science. In these textbooks a new tradition was born in which laboratory work came to be seen as central to the study of physics as the new textbooks and courses were called.

The fourth section of this chapter, *Growth*, covered the period from 1886 to 1889 and described the further development of the nascent tradition of physics. First looked at is Harvard's adoption of a new optional admission examination in physics by experimentation, followed by the pamphlet, written by Edwin Hall (Harvard, 1887) to support this new exam. Two further national reports (NEA, 1887 and AAAS, 1888) are reviewed as pressure mounted for teachers to change how the physical sciences were being taught. A second textbook by Alfred Gage (1888) was published during this period, as well as a laboratory manual by Horatio Chute (1889) both of which helped propel the new tradition forward. The second text by Gage (1888) showed not only the strength of demand, but also the continued evolution of the new tradition as Gage sought to incorporate improvements to his now popular approach. Chute's manual, designed to support textbooks which perhaps did not include any laboratory exercises, indicated another strategy for advancing the tradition; older textbooks of the natural philosophy tradition could be made more current by simultaneous use of a manual focused exclusively on laboratory investigations.

The final section, *Maturation*, of this fourth chapter examined the ways in which the tradition of physics evolved as it gained popularity. This was a period of consensus building during which laboratory investigations emphasizing quantitative results and deductive reasoning came to dominate and displace earlier emphasis on qualitative and inductive work. Textbooks exemplifying this period include Arey (1890), Hall and Bergen (1891), Carhart and Chute (1892), Gage (1895), and Avery (1895). The period also included the publication of the *Report of the Committee of Ten* (1893), the first attempt at establishing national guidelines for all high school subjects. Although seen later as a "symbol of the failure of the schools to react sufficiently to social change and the changing school population" (Kliebard, 1995, p. 13), at the time this *Report* was seen as, "an event of capital importance to educators" (Sizer, 1964, p. 148). The report included the recommendations of the conference on *Physics, Chemistry and Astronomy* which consolidated the victory of *Physics* over *Natural Philosophy* and established the centrality of the laboratory method to instruction in the physical sciences.

CH 5: CONCLUSION -- FAST FORWARD

As the twentieth century progressed, schools changed, and with them so did science instruction. Throughout, the good of the student was emphasized, but what was deemed best for the student changed with the needs and demands of society. Ultimately, schools served both student and community, with society dictating what was most needed in its future citizens. The points of debate, content mastery versus personal development, mental discipline versus emotional engagement continue today as schools fight for student retention and struggle to teach 21st century skills. Otero & Meltzer (2017), reflecting an increased attention to "discipline-specific" histories of science education, look to the past to address questions not only *how* science was to be taught, but also *to whom* and *to what end,* in order to improve teacher preparation today. The *Next Generation Science Standards* represent current efforts to deepen and enrich science education as they continue to answer these persisting questions which define the struggle around the science curriculum in America.

This research was born out of interest with the Next Generation Science Standards, and my own questions about whether they could affect any real change in how science is taught in the USA. This led to further questions about how I currently taught science and how it "ought" to be taught. Unable to find answers in my own direct experience, I became increasingly interested in the history of science and science education. The arguments which framed public discussion concerning the shape and limits of public education seem to reawaken when similar questions are asked in the present. In particular I will examine the historical development of science education in America and attempt to relate the issues of today with the lessons we could have learned from the past.

In the history of U.S. physics education, one finds a tension between providing real life applications and preparing scientists arising concurrent with the emergence itself of science as a school subject (Rudolph & Meshoulam, 2014). The historic debates over physics instruction have also been framed as a tension between "those emphasizing laboratory experiments" and reformers who in 1910 favored "interesting, practical science content" has been recently recognized (NRC, 2005). The *Next Generation Science Standards* are nothing if not ambitious, they attempt to transcend divisions and, as Dewey wrote, "to discover a reality to which each belongs" (1902, p. 8). The new standards merge together a number of long-standing aims of science education: to deliver a high-quality education to all students, address issues of equity, integrate science and engineering, attract students to the STEM fields (Science, Technology, Engineering and Technology), prepare students for college and careers, and provide authentic learning experiences reflecting the way professional scientists and engineers work.

The New Standards: An Overview

In answering how the past history of struggles over the physics curriculum are reflected in the new science standards, I begin by dissecting what lies within the *Next Generation Science Standards* (2013). The features of the new standards can be summarized under two guiding questions: how science is to be taught, and to whom? One finds the marks of history in the answers to both questions. Published in 2013 and adopted by Hawaii in 2016, the new standards are based around the findings presented in *A Framework for K-12 Science Education,* by the National Research Council (NRC, 2012). The *Framework* laid out, "A new vision for science education is considered the "foundational document" for the new science standards. All students according to this vision are to develop five qualities: an aesthetic appreciation of science; the knowledge needed to be informed citizens; the habits of thought required to careful consume information; the ability to learn science outside of school; and the skills needed to choose their own careers.

Written by a consortium of 26 "lead states" with the facilitation of Achieve, Inc., the *NGSS* are launched with an impressive discourse on the need for quality science education. Given the centrality of the new standards to this essay, it is worth citing the opening passage in full. Examining the exact phrasing reveals more about the intent of the new standards and the wide impact they hope to have.

> There is no doubt that science—and therefore science education— is central to the lives of all Americans. Never before has our world been so complex and science knowledge so critical to making sense of it all. When comprehending current events, choosing and using technology, or making informed decisions about one's health care, science understanding is key. Science is also at the heart of this country's ability to continue to innovate, lead, and create the jobs of the future. All students—whether they become technicians in a hospital, workers in a high-tech manufacturing facility, or Ph.D. researchers—must have a solid K–12 science education (NGSS Lead States, 2013, p. xiii).

According to the authors, no longer can we teach the esoteric minutiae of science to a gifted few given the centrality of science and technology to our society. All students must now have the ability to make "sense of it all." A word search of the new standards reveals the phrase "all students" is used one hundred thirty-two times across eleven sections, underscoring the intent for these standards to focus not only on future scientists, but on the wide range of students who attend America's public schools. Not only must science impart knowledge, but also all students must learn scientific modes of thought needed to evaluating choices and the skills required to take on jobs vital to the welfare of the country. The passage thus begins the discussion about *to whom* and *to what end* science ought to be taught.

The question of *how* students are to learn science lies at the heart of the new standards and is found in the equal emphasis on 1) habits of mind (the *Cross-Cutting Concepts*), 2) habits of inquiry (the *Science and Engineering Practices*), and 3) the traditional content knowledge (the *Disciplinary Core Ideas*). These *three dimensions,* as they are known, of the *Framework* became the pillars around which the NGSS were built; they mark a fresh attempt at trying to capture what science education ought to look like, describing what students ought to know, do, and consider as they grapple with natural phenomena. As supplemental materials to the NGSS make clear, students must do more "figuring out" and less "learning about" (Nextgenscience.org, 2016). The three dimensions, taken together, form *Performance Expectations* (PE) which represent the sort of learning expected of students. Each PE is a unique combination of a *concept,* a *practice* and an *idea.* An example taken from the new standards for high school physics is for students to, "develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects)" (HS-PS3-2). Below I show how this expectation reflects the three dimensions of the standards. The basic premise of the new standards is that all students must be immersed in authentic learning experiences if they are all to achieve the goals set out above.

In the example given, the concept is that of energy never being created or destroyed, only moving between and within things; this is a *cross-cutting concept,* reflecting the way a scientist or engineer would begin thinking about a whole suite of related problems. The practice is that of creating explicit and explanatory models of how things work; making models are a *scientific and engineering practice* as it is part of what these professionals do in the process of understand natural phenomena. The idea is that energy is a quantifiable property, which takes different forms, and is best understood at the microscopic scale. This constitutes a *disciplinary core idea* as it defines energy, making up part of the knowledge a person must possess to be scientifically literate. The answer of *how* science is best taught is: as similar as possible to the experiences of scientists and engineers. Students are to inquire, practice and investigate. This balancing of knowledge with actions and modes of thinking is grounded in current research on how students learn, but also reflects enduring ideas that can be found in the literature of more than a hundred years ago.

Historical Parallels

Having examined to some extent the intent and structure of the new science standards, we now turn to examine the way in which they reflect long enduring debates in the history of science education. Two scholars recently submitted a paper looking at what could be learned from, "100 Years of Attempts to Transform Physics Education" (Otero & Meltzer, 2016). In an earlier paper, the same scholars pointed out the degree of similarity between recommendations put forth over a hundred years ago, and those being put forth today (Meltzer & Otero, 2015). The similarities can be so strong between past and present that, "in some cases, it is difficult to determine whether a quotation came from an article by a physics instructor published in 1912 or from a report by a national commission issued in 2012" (Ibid, p. 447). It is not made clear who is referred to, but the 'national commission' is most likely the National Research Council, with the report being the *Framework;* the 'physics instructor' most likely was either Charles R. Mann or John. F. Woodhull. Both were leading physics reforms in new directions, the emphasis of which mirror efforts today. Mann was a leader of the *New Movement* among physics teachers, while Woodhull championed the *project method.* The parallels between past and present, however, go back further than 1912.

Today students are again called to gain a sense, "of the beauty and wonder of science" (NRC, 2012), a call which is deeply reminiscent of Herbert Spencer's claim that, "those who have never entered upon scientific pursuits know not a tithe of the poetry by which they are surrounded… indifferent to the grandest phenomena" (1866, p. 83). The term *phenomena*, used by Spencer to refer to as something at the heart of the scientific enterprise, also resurfaces in the *Next Generation Science Standards.* The centrality of "phenomena" in the new vision of science is shown in the three hundred eighty-eight times the term is used, being found across ten different sections of the document (NGSS Lead States, 2013). A supplementary publication, "Using Phenomena in NGSS" defines *phenomena* as "observable events that occur in the universe and that we can use our science knowledge to explain or predict" (Nextgenscience.org, 2016, p. 1). Phenomena are seen as central to the scientific enterprise in the NGSS; it is what scientists study. "The goal of building knowledge in science is to develop general ideas, based on evidence, that can explain and predict phenomena" (Ibid, p. 1). Yet this is nothing new; phenomena, and the study of the natural world through direct observation and laboratory investigations, were also at the center of late 19th and early 20th century physics reforms.

Sometimes what is most surprise is how the same reforms were, "rediscovered in each era as the intense and passionate debates of previous times were largely forgotten or overlooked" (Meltzer & Otero, 2015, p. 447). Indeed, the push for "the meaningful learning of science concepts derived from direct contact with the natural world" is actually DeBoer's description of what scientists advocated in the second half of the 19th century, in which the laboratory was "the place where skills in observation and inductive reasoning powers would be developed." (1991, p. 17). While it goes back well over a hundred years, the call for students to study science more from nature and less from textbooks remains with us today.

This need for students to actually investigate and *figure out* natural phenomenon, not just learn *about* them, is one of the parallels between the NEA *Report* of 1893 and the NRC *Framework* of 2012. The very first recommendation made by the conference on *Physics, Chemistry, and Astronomy* to the *Committee of Ten* was, "that the study of simple natural phenomena be introduced into the elementary schools and that this study, so far as practicable, be pursued by means of experiments carried on by the pupil" (NEA, 1893, p. 117). The same report continued, "It requires no argument to show that the study of a textbook of Chemistry or of Physics without laboratory work cannot give a satisfactory knowledge of these subjects and cannot furnish scientific training. Such study is of little, if any, value" (NEA, 1893, p. 119). Science has always more than a body of facts, although too frequently it is taught as such; it is a process which seeks to build coherent explanations of the living and nonliving universe through observation and investigation.

The intent, found also in the NGSS, of having students conduct investigations, was not to abolish all reading of textbooks, but rather to avoid reliance on received knowledge. The goal was to balance learning from multiple sources; this is seen in the rejection of solely relying on lab work. "The mere performing of experiments in a laboratory, however well-equipped the laboratory may be, cannot accomplish what is desired" (NEA, 1893, p. 119). A student, "may work conscientiously in the laboratory, and study his text-book thoroughly, and yet receive a very inadequate training. He needs an intelligent teacher to aid him in interpreting the statements of the book and the phenomena observed, as well as to show him how to work" (Ibid., p. 119). A proper science education, then as now, required the comparison of lab results with what was previously known in the literature and to be discussed and shared with the teacher. In today's standards, one finds this written into the *Science & Engineering Practice* (SEP) of "*Obtaining, evaluating, and communicating information*" (NGSS Lead States, 2013, p. 428). While direct student engagement with phenomena is emphasized, the new standards also indicate the important role of discussions around the findings, as exemplified in the SEP of *"Engaging in Argument from Evidence"* (Ibid., p. 426). Vigilant teachers are needed to ensure that the desired learning outcomes are met. Science then, as now, is a multifaceted process that students best learned by doing, as best as they were able, what scientists do.

What is "called 'inquiry' or 'scientific practices' in more recent times" is essentially the same as the "inductive method" advocated over a century ago (Meltzer & Otero, 2015, p. 447). Incorporated in each performance expectation, scientific practices are indeed heavily emphasized in the new standards, forming a full third of the NGSS. The phrase "*science and engineering practice"* (or SEPs) is used three hundred and nine times throughout the new standards, with an additional sixty-two appearances of the term "inquiry" (NGSS Lead States, 2013). However, a simple equation of the current terms with the inductive method is a bit slick. As Wead wrote, "Some common expressions are ambiguous and therefore convey no definite meaning unless specially defined", his example was that "*practical* is a word which has been so abused that it is better to drop it from the discussion" (1884, p. 12). The SEPs actually contain both inductive and deductive practices, and in one case "developing and using models" combines both in the same practice. Despite this, there is value in comparing the *practices* of today with the *inductive method* of the late 19th century.

In “Aims and Methods of the Teaching of Physics”, a key early document in history of American physics education, Wead describes the “inductive method” as one of five means by which “new truth” can be acquired (the other four being: observation, deduction, experimentation, and dogmatic authority). The five methods were not mutually exclusive, indeed they could be applied in various combinations, but “the name-giving, vitalizing thing is the induction of the principle or law by an active mental operation, instead of the passive reception of it from authority, or from a priori considerations, as the ancients did” (Wead, 1884, p. 180). This method followed “the scientific method” in which “we first observe the phenomena sharply and then seek for a cause or for the law according to which the forces act” (Ibid., p. 118). Such a statement is indeed very much in line with the intent and even vocabulary of the new standards, however Wead already recognized two difficulties in implementing the method. The first difficulty was, “the teacher has probably known little or nothing of it in his own education” and the other that “the progress of the student following this method is so slow, if measured by the usual examination tests, as to discourage a faint heart” (Ibid., p. 117). While Wead was convinced his discussion showed the difficulties could be overcome, both challenges remain in effect.

“The ‘inductive method,’ or the method of discovery, is often overworked, with the result that it must break down or be continued as a mere pretense”, declared Edwin Hall in, *The Teaching of Chemistry and Physics in the Secondary School* (1902, p. 275). Hall distinguished the inductive method, which he saw as asking students to *rediscover* scientific truths, from that of *inquiry* which he recommended. The difference, on closer examination, reduces however to a matter of degree.

> I would keep the pupil just enough in the dark as to the probable out outcome of his experiment, just enough in the attitude of discovery, to leave him unprejudiced in his observations, and then I would insist that his inferences, so far as they profess to be derived from his own seeing, must agree with the record, previously made and unalterable (Ibid., p. 278).

For all practical purposes this is a description of the inductive method. What Hall fought against was not so much induction per se, but the tendency to take the method of induction to the extreme. He provides an example of such, in which students are asked to "watch intently for some time a bit of wood lying on a table, and then, after reflection, to write down the inference, *Matter cannot set itself in motion"* (Ibid., 275). Such an assignment, asking students to rediscover of Newton's first law based on no experimentation and virtually no investigation, was and is an absurd abuse of the inductive method. Instead Hall, like Wead before him and the NGSS today, wanted students to build an explanation out of their own learning.

One also finds strong parallels, between the work of the *Committee of Ten* and the NGSS, in the attempt to reach all students. It was a proud proclamation in the general report of 1893 that,

> Ninety-eight teachers, intimately concerned either with the actual work of American secondary schools, or with the results of that work as they appear in students who come to college, unanimously declare that every subject which is taught at all in a secondary school should be taught in the same way and to the

same extent to every pupil so long as he pursues it, no matter what the probable destination of the pupil may be, or at what point his education is to cease" (NEA, 1893, p. 17).

This statement was echoed in *Resolution 11* of the conference on *Physics, Chemistry and Astronomy* which stated, "That there should be no difference in the treatment of Physics, Chemistry, and Astronomy, for those going to college or scientific school, and those going to neither" (Ibid, p. 118). In both passages, one can clearly see the attempt to teach all students the same regardless of their later "destination." While this mirrors the intent of the NGSS today, which proclaims, "all standards, all students" (NGSS Lead States, 2013, Appendix D), there are important distinctions to be drawn.

The members of the Committee of Ten sought to resist was what is now referred to as *tracking*, where students are sorted based on their expected post-secondary outcome (college or career) and therefore received different instruction. It was intended that, "the colleges and scientific schools should be accessible to all boys or girls who have completed creditably the secondary school course" (NEA, 1893, p. 52), which equates quite well with today's imperative, "to enable all students to be college and career ready" (NGSS Lead States, 2013, p. 392). However, in 1893, the student population of America's secondary schools were still homogenous enough to hope that all students could be taught in the same manner *without differentiation*. Today's efforts are more sophisticated, if also more abstruse; students are to be taught differently, yet cover the same concepts, ideas, and practices. Teachers are asked to teach the same standards to all students, while differentiating the content and "making diversity visible"

(Ibid., p. 393). In the 1900s, as student enrollment, and diversity, continued to increase, tracking in the name of *social efficiency* became more popular.

Comparing the reports of 1893 and 1918 one sees the tension John Rudolph has called the “practical-abstract continuum” (Rudolph & Meshoulam, 2014, p. 1). This tension manifests itself as a division between the goals of developing future scientists and fostering an informed citizenship. The *Committee of Ten*, attempting to align the expected outcomes of schools with the entrance requirements of colleges in 1893, held certain principles which are still reflected in the new standards today: all students ought to be taught the same regardless of future destination, even at the elementary level science be taught through “natural phenomena,” and a proper study of physics required a balance of methods, “a combination of laboratory work, text-book, and thorough didactic instruction carried on conjointly” (NEA, 1893, p. 117-118). Yet schools had continued to change as enrollments changed dramatically. By 1918, the *Commission of the Reorganization of Secondary Education* (CRSE) felt that a “extensive reorganization” of secondary education was “imperative” given the “failure to make adjustments” as needs had arisen (NEA, 1918, p. 7).

The focus of education needed to be on, “nothing less than complete and worthy living for all youth” (Ibid., p. 32). The ramifications for science education followed two years later, with a report on the *Reorganization of Science in Secondary Schools* (NEA, 1920). Reference to the specific knowledge, habits, powers, interests, and ideals that should be developed” were to come second to the principles laid out in 1918. Namely the value of science education became framed in terms of its ability to contribute to “health, worthy home membership, vocation, citizenship, worthy leisure, and ethical character” (Ibid., p. 12). This was quite a reversal from the recommendations of 1893, with their strong focus on science for the sake of science. While the committee in 1893 never thought, “The preparation of a few pupils for college or scientific school” should not be the “the principal object” of a public high school, they found it desirable that, “the colleges and scientific schools should be accessible to all boys or girls who have completed creditably the secondary school course” (NEA, 1893, p. 52). By 1920, this emphasis on preparing all students for college and career had disappeared. Instead, vocational education was in high demand, as were all things *practical,* that same word which Wead had sought in 1884 to eliminate from educational discourse.

With classrooms bulging in size, the search was on for making the curriculum meaningful to more students. The trouble was, “Science for high-school students has been too largely organized for the purpose of giving information and training in each of the sciences” rather than being designed for accessibility and intriguing (NEA, 1920, p. 16). “The common method” of teaching science omitted, “the commonplace manifestations of science in home, community, civic, and industrial situations which make it most easily possible for the learner to practice science” (Ibid., p. 16). Students needed to see the connection of science with their world. Clearly, the call for students to study more natural phenomena in 1893 had not been heard, or if heard been poorly followed.

Laboratory work, while not abandoned, also needed to be reorganized given that, “laboratory work in general has not accomplished the results expected” (Ibid., p. 19). Four reasons were given for this: labs too often had students verify what they already knew, the experiments repeated what was explained in the book, data was collected as an end-in-itself, and many were too minutely quantitative for the student to comprehend. Interestingly enough, all four reasons indicated the inductive method had not been properly used. The likes of Wead and Hall would have taken issue with such lab investigations as well. As generally the case, great pedagogy poorly applied leads to poor results. The problem was not with the older methods themselves, but in how they had been used (or abused).

When one examines the reports of the sub-committees, the pattern continues. Student boredom was the number one reason physics instruction needed to be revised. “The content and methods of presentation in vogue for the past 20 years have failed to make a vital appeal to most pupils. With the large majority the subject has aroused little enthusiasm” (NEA, 1920, p. 49). Four reasons were given: the content followed a traditional, logical sequence rather than student interest; it was assumed that principles could be grasped if only defined clearly enough; the lab and the classroom were disconnected; and the content was not connected with its applications in various vocations.

The solution was to adopt the “problem-project-topic method” of science teaching (NEA, 1918, p. 20). The method called for starting, “with questions of immediate interest to the pupil” and then with “interest as a spur” having the pupil turn “his energies to the solution of a problem which really engages him” (Ibid., p. 16). In physics, the principles of mechanics could be,

> Approached naturally and inductively through projects and problems connected with steelyards and balances, balancing toys, and "meccano" sets; sewing machines, washing machines, and wringers… bicycles and motorcycles, automobiles and farm-tractors, wind mills, waterwheels, and turbines, cream separators, motor boats, and sailboats (Ibid., p. 59).

The Report on the *Reorganization of Secondary Science* seemed a return to “object lessons” introduced to science education in the 1860s, only now the objects were more technologically advanced. The general idea was clear, engage students with familiar objects, and seek to lead them from there to fundamental principles by means of individual and group projects. Everyday objects were apparently to take the place of specific lab exercises, but what was to prevent such investigations from becoming little more than show and tell?

There is much in this description of science which feels familiar and comparable with the intent and content of the new standards. Early 19th century schools may have become organized around the factory principle and functioned as a place for social sorting of young people, but they also aspired to teach science as relevant to children's lives by having students investigate common objects. The real difference between periods, between the late 19th, early 20th, and now the early 21st century, seems less in the intent or purpose of the science pedagogy, and more in how it was applied, or misapplied. The concepts for example of *phenomena* and *inductive reasoning* continue to appear in the discussions of how science ought to be taught, but one questions the progress made in realizing them.

The new *Next Generation Science Standards* (NGSS Lead States, 2013) represent a sophisticated effort to bring together again the goals of preparing future scientists and providing real life applications, in the hopes of making school science more like the work of professional scientists and engineers. This remarkable and impressive attempt at synthesis is reminiscent of Dewey's efforts to resolve the child or the curriculum dichotomy. As Dewey explained, "It is easier to see the conditions in their separateness, to insist upon one at the expense of the other, to make antagonists of them, than to discover a reality to which each belongs" (Dewey, 1902, p. 8). Perhaps, indeed, this has been the central problem in science education; it is simpler to see things in their individual pieces, than in their connectedness. Teachers, rarely sufficiently supplied with time, training and equipment, can scarcely be blamed for taking the easier path. Teachers tend to divide up material into neat individual lessons centered around those central facts that appear consistently on state exams. To change student outcomes requires more than a new set of standards, it requires improved conditions and support for teachers.

Recommendations

Previously I claimed the study of history is often justified by providing the scholar a clearer understanding of not only the past, but also of their own present circumstances. Such improved understanding is valued for its ability to lead to clearer thinking and better judgement. Studying the history of how high school physic emerged and acquired the central identity it still has today, makes the following recommendations clear. These recommendations relate to the place of inductive inquiry in high school science, the quality of teachers, and the need for science to be conducted in the service of humanity. Not recorded in any particular historical source consulted, they represent the accumulated wisdom and true fruit of this research and the author's experience as a high school teacher, instructional coach, and school-level leader. They are born of reflection and passion.

There are limitations to the amount of inductive inquiry which high school students can reasonably conduct. Such line of experimentation, which asks students make their own observations and from these hypothesize an explanation (often now called open-ended inquiry), is a challenge to those who lack a larger body of experience to draw upon. However, the opposite practice of excessive amounts of deductive work stifle curiosity and creativity and so must be balanced. Ideally, inductive work is mixed in with the more straight-forward deductive work to keep students engaged and foster their creativity, while not leading to futile and exasperating frustration at not being able to make sense of a handful of experiments. As students are drawn in and gain more familiarity with the scientific exploration of phenomena, more inductive work can be expected of them. In an era of Big Data, where the challenge is more often making sense of huge amounts of information, the ability to sort, organize, and then recognize emerging patterns requires experience in inductive reasoning. This means that while students may require sufficient deductive work to get a feel for an area, they must then be required to try their hands at generating their own explanations. This is very much in line with the goals of the NGSS science standards.

The quality of a student's learning experience depends to the greatest extent on the quality of the teacher. The best teachers, those who make a lasting, positively transforming impact on their students, are those passionate about both their craft and their content. The craft of teaching well is now seen to require empathy and the ability to create positive relationships with students, and between students. These relationships can then be leveraged to create classrooms which function at higher levels and produce greater learning. Students learn far more from teachers who care, and care deeply, then from those who are simply seeking to survive and keep their own heads above water. The true secret to better student learning and outcomes is not better standards but recruiting and retaining better teachers. Unfortunately, too often in American society, teachers are not seen as professionals on the same level as lawyers, doctors or engineers. Until a teaching career is just as attractive as those other options, the best and brightest will choose not to teach, but to use their scientific passions to pursue more lucrative, respected and fulfilling careers. We cannot expect the same quality of work from the educational profession as we have in law, medicine and technology until teachers are fed with the same diet of respect, rigor, and reward as the other professions.

Students must also be taught that the purpose of science is to serve humanity. This goal, of using science and the technology it engenders to benefit both the species and the host environment upon which it depends, is essential to ensuring the well-being of all. It is not enough for technology to enrich or empower the individual, it must improve the common weal, and the environment as well. The world has become a highly inter-connected place where our economies are largely dependent on stability in other parts of the world in order to maintain supply chains and markets. Given how technologically dependent our societies have become it is of paramount importance that the next generation of hardware and software developers are taught to value individual sovereignty in order to design advances which facilitate and liberate our better virtues. Technology is neither inherently good or evil, it is the means and ends by which it must be judged. Technology can be freeing or enslaving depending on how it is designed and used, and the process of enhancing its positive influence begins in teaching our children in school the value and importance of ethics and how it lies at the heart of the scientific endeavor.

Chapter Summary

This final chapter has brought the dissertation to a close by considering the NGSS, parallels between past and current reform efforts, and a set of recommendations based upon the knowledge gained from this research blended with first-hand experience teaching and working in America's public-school system. The NGSS are part of a broader effort to improve public education in America by improving the content standards. This approach to reform, known as standards-based reform, includes the Common Core efforts. Rather than addressing issues of teacher quality such as training, support, and retention, it takes an indirect approach and seeks to influence what is taught by laying out a new basis for the science curriculum. If the adult who directs the learning is not addressed, these standards will achieve nothing of significance no matter how thoughtfully they are crafted and how much richer and more complex they are. To create lasting change in the classroom, teachers need to be supported directly with better preparation, better opportunities to learn while working, and more rewarding working conditions. Current statements about how teachers must teach, and students must learn sound remarkably similar to past statements made over a hundred years ago. The conversation needs to change and focus on how to improve teacher quality: how to recruit, train-up, and retain people with the required knowledge, skillset and passion to make the change and do the hard work required. The secret to improving America's physics education lies not in what is written, but in what is done to support and improve its teachers.

REFERENCES

AAAS Committee on Science Teaching in the Public Schools [E. L. Youmans, A. R. Grote, J. W. Powell, N. S. Shaler, and J. S. Newberry], (1881). Report of Committee on Science Teaching in the Public Schools, *Proceedings of the American Association for the Advancement of Science, Twenty-Ninth Meeting, held at Boston, Mass., August 1880*, pp. 55-63. Putnam, F. W. [Ed]. Salem, MA: Salem Press. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

AAAS Committee on Physics Teaching [T. C. Mendenhall, Chairman; Wm. A. Anthony, H. S. Carhart, and F. H. Smith], (1888). Report of the Committee on Physics-Teaching, *Proceedings of the American Association for the Advancement of Science, Thirty-Seventh Meeting, Held at Cleveland, August 1888*, pp. 28-34. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Arey, A. L. (1890). Methods of teaching physics. *The Academy,* 6(1), 36-41. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Avery, E. M. (1878). *Elements of natural philosophy, a textbook for high schools and academies.* New York, NY: Sheldon & Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Avery, E. M. (1884). *First principles of natural philosophy, a textbook for common schools.* New York, NY: American Book Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Avery, E. M. (1895). *School physics, a new textbook for high schools and academies.* New York, NY: Sheldon & Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Bachman, F. P. (1918). *Great inventors and their inventions.* New York, NY: American Book Company.

Bailyn, B. (1960). *Education in the forming of American society: Needs and opportunities for study.* Chapel Hill, NC: University of North Carolina Press.

Butterfield, H. (1931). *The Whig interpretation of history* [Kindle Cloud Reader edition]. Retrieved from Amazon.com.

Carhart, H.S., & Chute, H.N., (1892). *The elements of physics*. Boston, MA: Allyn and Bacon. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Chase, C. (2015). *Surviving AI* [Kindle Cloud Reader edition]. Retrieved from Amazon.com.

Chilisa, B. (2012). *Indigenous research methodologies*. Los Angeles, CA: Sage Publications.

Clarke, F. W. (1880). *A report on the teaching of chemistry and physics in the united states* [Circulars of Information of the Bureau of Education, No. 6—1880]. Washington DC: Government Printing Office. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Chute, H.N. (1889). *Elementary practical physics: a guide for the physical laboratory*. Boston, MA: D.C. Heath & Co. Reprinted by Scholar Select.

Constitution of the United States (1787). U.S. National Archives. Retrieved from: https://www.archives.gov/founding-docs/constitution-transcript

Cooley, L. R. C. (1872). *Natural philosophy for common and high schools.* New York, NY: Scribner, Armstrong & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Counts, G. S. (1962). *Education and the foundations of freedom*. Pittsburgh, PA: University of Pittsburgh Press. Retrieved from http://digital.library.pitt.edu/cgi-bin/t/text/text-idx?c=pittpress;cc=pittpress;q1=Education;rgn=works;rgn1=topic;view=toc;idno=31735057898060.

Cremin, L.A. (1964). *The transformation of the school: progressivism in American education 1876-1957.* New York, NY: Vintage Books.

Cremin, L.A. (1965). *The wonderful world of Ellwood Patterson Cubberley.* New York, NY: Teacher College Press.

Deboer, G. (1991). *A history of ideas in science education: Implications for practice.* New York, NY: Teacher College Press.

Declaration of Independence (1776). U.S. National Archives. Retrieved from: https://www.archives.gov/founding-docs/declaration-transcript

Dewey, J. (1902). *The child and the curriculum.* Chicago, IL: University of Chicago Press. Retrieved from: https://play.google.com/store/books/details?id=lJEjAAAAMAA

Dewey, J. (1916). *Democracy & education*. New York, NY: MacMillan.

Dewey, J. (1939). *Freedom & culture.* Amherst, NY: Prometheus Books.

Donahue, D. (1993). Serving students, science, or society? The secondary school physics curriculum in the united states, 1930-65. *History of Education Quarterly*, 33(3), 321-352. doi:1. Retrieved from http://www.jstor.org/stable/368196 doi:1

Eliot, C. W. (1909a). Education for efficiency. In H. Suzzallo, (Ed.) *Education for Efficiency and The New Definition of the Cultivated Man*. Cambridge, MA: Houghton Mifflin Company.

Eliot, C. W. (1909b). The new definition of the cultivated man. In H. Suzzallo, (Ed.) *Education for Efficiency and The New Definition of the Cultivated Man.* Cambridge, MA: Houghton Mifflin Company.

Frey, C. B., & Osborne, M. A. (2013). *The future of employment: how susceptible are jobs to computerization.* Retrieved from http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf

Gadamer, H. G. (1988). *Truth & method* (Continuum Edition) [Kindle Cloud Reader edition]. Retrieved from Amazon.com. (Original work published 1960).

Gaddis (2002). *The landscape of history: How historians map the past* [Kindle Cloud Reader edition]. Retrieved from Amazon.com.

Gage, A. P. (1882). *A text-book on the elements of physics for high schools and academies*. Boston, MA: Ginn, Heath, and Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Gage, A. P. (1888). *Introduction to physical science.* Boston, MA: Ginn, Heath, and Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Gage, A. P. & A. W. Goodspeed (1888). *The principles of physics.* Boston, MA: Ginn, Heath, and Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Gaither, M. (2012). Is it time for another historiographical revolution? *History of Education Quarterly*, *53*(2), 177-183.

Galileo (2012). A sidereal message, in *Selected Writings*. (W. R. Shea & M. Davie: trans.). New York, NY: Oxford University Press. (Original work published 1610)

Galgano, M.J., Arndt, J.C., & Hyser, R.M. (2008). *Doing history: research & writing in the digital age.* Belmont, CA: Wadsworth Press.

Gribetz, M. (2016). *A glimpse of the future through an augmented reality headset.* TED2016. Retrieved from: https://www.ted.com/talks/meron_gribetz_a_glimpse_of_the_future_through_an_augmented_reality_headset#t-428194

Hall, E. H. & Bergen, J. Y. (1891). *A textbook of physics, largely experimental: on the basis of the Harvard College "Descriptive list of elementary physical experiments.* New York, NY: Henry Holt. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Harris, W. T. (1895). *How to teach natural science in public schools*. Syracuse, NY: C. W. Bardeen.

Harvard College. (1886). *Provisional list of experiments in elementary physics for admission to college in 1887*. [predecessor to descriptive list] Cambridge, MA: Harvard University. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Harvard University. (1887). *Descriptive list of experiments in physics. Intended for use in preparing students for the admission examination in elementary experimental physics.* Cambridge, MA: Harvard University. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Heering, P., Wittje, R. (2011). *Learning by doing: Experiments and instruments in the history of science teaching.* Stuttgart, Germany: Franz Steiner.

Howatson, M. C. (1989). *The Oxford companion to classical literature* (2nd Ed.). New York, NY: Oxford University Press.

Jowett, B. (1972). *Plato: the republic*. Norwalk, CT: Heritage Press.

Kaestle, C. F. (1983). *Pillars of the republic: Common schools and American society, 1780-1860.* New York, NY: Hill & Wang.

Kelly, W. C. (1955). Physics in the public high school. *Physics Today, 8*(3), 12-14. doi: 10.1063/1.3061943

Kipman, A. (2016). *A futuristic vision of the age of holograms.* TED2016. Retrieved from: https://www.ted.com/talks/alex_kipman_the_dawn_of_the_age_of_holograms

Kliebard, H. M. (1995). *The struggle for the American curriculum,* 1893-1958. (2nd ed.). ....New York, NY: Routledge.

Krug, E.A. (1969). *The shaping of the American high school*: 1880-1920. Madison, WI: University of Wisconsin Press.

Lagemann, E. C. (2005). Does history matter in educational research? A brief for the humanities in an age of science. *Harvard Educational Review, 75*(1), 9-24.

Marshall, C., & Rossman, G. B. (2011). *Designing qualitative research.* 5th Edition. Los Angeles, CA: Sage.

Meltzer, D. E., & Otero, V. K. (2015). A brief history of physics education in the United States. *American Journal of Physics*, *83*(5), 447-458. doi: 10.1119/1.4902397

Meltzer, D. E., & Otero, V. K. (n.d.). Master Bibliography - History of US Physics Education. Retrieved from https://sites.google.com/site/physicseducationhistory/master-bibliography

Monroe, P. (1905). *A textbook in the history of education.* New York, NY: MacMillan & Co. Retrieved from:

https://play.google.com/store/books/details/Paul_Monroe_A_Text_book_in_the_History_of_Educatio?id=QK8AAAAAYAAJ

Moyer, A. E. (1976). Edwin Hall and the emergence of the laboratory in teaching physics. *Physics Teacher,* 14(2), 96-103.

National Educational Association. (1887). Report of the Committee on Physics-Teaching. *Journal of Proceedings and Addresses of the National Educational Association, Session of the year 1887*, 41-44. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

National Education Association. (1893). *The report of the committee of ten on secondary school studies.* Washington, DC: U.S. Government Printing Office.

National Education Association. (1918). *Cardinal principles of secondary education: a report of the commission on the reorganization of secondary education.* Washington, DC: U.S. Government Printing Office.

National Education Association. (1920). *Reorganization of science in secondary schools.* (US Bureau of Education, Bulletin No. 26). Washington, DC: U.S. Government Printing Office.

Nextgenscience.org. (2016). *Using phenomena in NGSS-designed lessons and units.* Retrieved from: http://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

NGSS Lead States. (2013). *Next generation science standards: for states, by states.* Washington, DC: National Academies Press. Retrieved from: https://www.nap.edu/download/18290

National Research Council (2005). *America's lab report: investigations in high school science.* Washington, DC: The National Academies Press. Retrieved from: https://www.nap.edu/download/11311

National Research Council. (2012). *A framework for K-12 science education: practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press. Retrieved from: https://www.nap.edu/download/13165

National Science Teachers Association. (2003). NSTA position statement: *Gender equity in science education*. Retrieved from http://www.nsta.org/about/positions/

National Science Teachers Association. (2011). NSTA position statement: *Quality science education and 21st-century skills.* Retrieved from http://www.nsta.org/about/positions/

Norton, S. A. (1870). *The elements of natural philosophy, eclectic education series.* Cincinnati, OH: Van Antwerp, Bragg & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

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 H. Geitz, J. Heideking, & J. Herbst, 129–153. New York, NY: Cambridge University Press.

Olmsted, D. (1833). *A compendium of natural philosophy: adapted to the use of the general reader and of schools and academies.* New Haven, CT: Hezekiah Howe and Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Otero, V. K. & Meltzer, D. E. (2016). 100 years of attempts to transform physics education. *The Physics Teacher* 54, 523; doi: 10.1119/1.4967888. Retrieved from: https://drive.google.com/file/d/0B3rcT2urDUl3bm9IaEtQaVZWRjQ/view

Parker, R. G. (1844). *The Boston school compendium of natural and experimental philosophy, embracing the elementary principles of mechanics, hydrostatics, hydraulics, pneumatics, acoustics, pyronomics, optics, electricity, galvanism, magnetism, electro-magnetism, & astronomy; with a description of the steam and locomotive engines* (12th Ed.). Boston, MA: Thomas H. Webb & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Peck, W. G. (1871). *Introductory course of natural philosophy for the use of schools and academies, edited from Ganot's popular physics*. New York, NY: A. S. Barnes & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Pickering, E. C. (1873). *Elements of physical manipulation.* New York, NY: Hurd & Houghton. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Plato, (2008). *The Republic*. (R. Waterfield; trans.). New York, NY: Oxford University Press. (Original work published 380 B.C.)

Quackenbos, G. P., (1860). *A natural philosophy: embracing the most recent discoveries in the various branches of physics, and exhibiting the application of scientific principles in every-day life.* New York, NY: D. Appleton and Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Quackenbos, G. P., (1871). *A natural philosophy embracing the most recent discoveries in the various branches of physics, and exhibiting the application of scientific principles in every-day life.* Revised edition. New York, NY: D. Appleton and Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Ramsey, P. J. (2007). Histories taking root: The contexts and patterns of educational historiography during the twentieth century. *American Educational History Journal*, *34* (2), 347–363.

Reece, W. J. (1995). *The origins of the American high school*. New Haven, NJ: Yale.

Rolfe, W. J., & Gillet, J. A. (1874). *Natural philosophy, for high schools and academies.* New York, NY: Potter, Ainsworth, and Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Rosen, S. (1954). A history of the physics laboratory in the American public high school (to 1910). *American Journal of Physics, 22*, 194-204. http://dx.doi.org/10.1119/1.1933679

Rousseau, J.J. (2013). *Emile*. (P. Constantine; trans.) In L. Damrosch, (Ed.) *The essential writings of Rousseau.* New York, NY: Modern Library. (Original work published 1762)

Rudolph, J.L. (2005). Epistemology for the masses: The origins of 'the scientific method' in American schools. *History of Education Quarterly*, *45,* 341-376. Retrieved from: http://www.amscied.net/Publications_files/2005-Rudolph%20HEQ.pdf

Rudolph, J.L., & Meshoulam, D. (2014). Science education in American high schools. In Hugh R. Slotten (Eds.), *Oxford Encyclopedia of the History of American Science, Medicine, and Technology*, (pp. 503-523). New York, NY, USA: Oxford University Press. Retrieved from http://www.amscied.net/Publications.html

Rury, J. L. (2002). *Education and social change*. New York, NY: Routledge.

Rury, J. L. (2006). The curious status of the history of education: A parallel perspective. *History of Education Quarterly* 46(4): 571-598. doi: 10.1111/j.1748-5959.2006.00032.x

Saldana, J. (2015). *Thinking qualitatively: Methods of mind.* Los Angeles, CA: Sage.

Schlabach, T. F, (1996). *The ten commandments of good historical writing: With apologies to the Author of the original ten.* Retrieved from http://www.geraldschlabach.net/about/relationships/benedictine/courses/handouts/historical-writing/

Sears, L. A. (n.d.). A short history of united states education, 1900 to 2006. *History of Literacy*. Retrieved from: http://www.historyliteracy.org/publications.html

Sizer, T. R. (1964). *Secondary schools at the turn of the century*. New Haven, NJ: Yale.

Shapin, S. (1996). *The scientific revolution.* Chicago, Il: University of Chicago.

Sketch of Frank Wigglesworth Clarke (1898). *Popular Science Monthly*. 54, 110-117. November. Retrieved from: https://en.wikisource.org/wiki/Popular_Science_Monthly/Volume_54/November_1898/Sketch_of_Frank_Wigglesworth_Clarke

Spencer, H. (1866). *Education: intellectual, moral, and physical*. New York, NY: Appleton & Co. Retrieved from: https://play.google.com/store/books/details?id=gztMAAAAIAAJ

Stevens, W. L. C. (1895). Review: the principles of physics. *Science New Series*, 2 (36). Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Steele, J. D. (1871). *A fourteen weeks' course in natural philosophy.* New York, NY: A.S. Barnes & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Steele, J. D. (1878). *Fourteen weeks in physics.* New York, NY: A.S. Barnes & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Taffel, D. (2004). "Introduction" in *The trial & death of Socrates: four dialogues.* New York, NY: Barnes & Nobles Press.

Trowbridge, J. (1879). The study of physics in the secondary schools. *Popular Science Monthly* 15: 159-166. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Trowbridge, J. (1886). *The new physics. A manual of experimental study for high schools and preparatory schools for college*. New York, NY: D. Appleton and Company. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Turabian, K. L. (2010). *A manual for writers of research papers, theses, and dissertations, Chicago style for students and researchers*, 8th Ed. Chicago, Il: Chicago University Press.

Tyack, D. B. (1974). *The one best system: A history of American urban education*. Cambridge, MA: Harvard University Press.

United States Bureau of the Census. (1949). *Historical statistics of the United States, 1789-1945, a supplement to the statistical abstract of the United States*. Retrieved from: https://books.google.com/ebooks/app#reader/WvcIAAAAIAAJ/GBS.PP1

Wagoner, W. J. & Urban, J. L., (2004). *American education: a history,* 3rd. Ed. New York, NY: McGraw Hill.

Waterfield, R. (2002). "Introduction" in *Phaedrus.* New York, NY: Oxford University Press.

Wead, C.K. (1884). *Aims and methods of the teaching of physics.* U.S. Government Printing Office. Retrieved from: https://play.google.com/store/books/details?id=uWhYAAAAYAAJ

Wells, D. A., & Ford, W. C. (1879). *Wells' natural philosophy: for the use of schools, academies, and private students,* New Edition. New York, NY: Ivison, Blakeman, Taylor, & Co. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography

Worthington, A. M. (1886). *A First Course of Physical Laboratory Practice*. London: Rivingtons. Retrieved from: https://sites.google.com/site/physicseducationhistory/master-bibliography