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Physics via history and philosophy:

The effects of studying primary sources on student achievement in an introductory physics course

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Abstract

Physics education experts express the view that the traditional, logically organized approach to physics instruction is lacking. The traditional approach not only intimidates all but the most-technically minded students from even taking physics, it fails to produce deep understanding of physics as a discipline—both the epistemology of physics and the methods by which physics advances. The result is that students tend to memorize physics theories rather than understanding them, and physics does not alter students' nonscientific beliefs. As an alternative, experts advocate the explicit teaching of the nature of science, its epistemology and methodology, through a context of the history and philosophy of science (HPS). While the benefits of this approach have been established, the HPS approach itself has largely not been tested in real classrooms. Of the several possible approaches to teaching HPS, one that is frequently mentioned is the use of primary sources, especially the original writings of scientists. This study proposes to look at the effects on student attitudes toward science and student understanding of physics principles of teaching introductory high school physics using primary sources within a context of history and philosophy of science.

"If there is one thing that physics teaching must avoid, it is to dull the natural curiosity of students by pretending to have answered the most basic questions about reality."

Brouwer and Singh (1983, p. 232)

"The history of science is science itself."

Goethe (quoted in Kauffman, 1989)

Introduction

In my young career as a high school physics instructor, I've become dissatisfied with what science historian Stephen G. Brush calls the traditional "logical" approach to teaching this discipline (1969, p. 271). Transmitting knowledge to students about the end products of scientific inquiry – theories, formulas, and problem-solving algorithms – can help students "develop … technical competence in the application of the laws of the discipline to particular cases" (Cushing, 1989, p. 54). But as Cushing adds, this is only one of the three goals every introductory science course ought to have. Such courses also should enable students to explain the phenomena of the physical world, and "give the student an appreciation of the corrigible nature of human knowledge, including scientific knowledge" (ibid).

Unfortunately, many high school students do not have an appreciation of the nature of scientific knowledge (Smith et al., 2000). Taught from textbooks that "portray science in a highly convergent, rational manner that may overwhelm the reader with a claim of authority and truth" (Martin & Brouwer, 1991, p. 707), and taught by teachers who themselves lack deep understanding about the nature of science (Arons, 1997; Brush, 1989), students are not likely to change their simplistic, incorrect ideas about the ways science develops and the fallibility of science knowledge unless a new approach to teaching science is adopted.

An alternative to the "logical" approach is a "historical" approach that would better represent the actual development of scientific ideas (Brush, 1969). In reality, theories are not handed down as if they were the Ten Commandments, but are created by individual people working in a particular historical and intellectual context. These very "laws" of science may also be revised or discarded as new evidence and/or new theoretical perspectives are developed (Brouwer & Singh, 1983; Carson, 1997; Cushing, 1989; Galili & Hazan, 2001; Kauffman, 1989). As Carson succinctly states, "the social and investigative processes that produce knowledge in science are part of the necessary description of the knowledge itself—an explication of those processes provides context, and it serves to qualify the nature of the knowledge" (1997, p. 112).

While a good number of high school physics classes no doubt focus on formulas, the need for issues in the nature of science to be taught at the high school level is recognized in the national education standards produced by the American Association for the Advancement of Science and the National Research Council (1993; 1996). These standards assert that to be scientifically literate, students should "develop understanding of science as a human endeavor [and the] nature of scientific knowledge" (NRC, 1996).

One of the ways the AAAS and the NRC recommend for teaching the nature of science is to incorporate history of science into the high school science class (1993; 1996). Many physics educators as well as experts in the history and philosophy of science (HPS) agree with this approach, giving several reasons why it would benefit students. However, while the theoretical basis for teaching HPS may be established, specific, practical methods for teaching it are hard to find, and there has been little research looking into how history and philosophy of science affects students in a physics classroom (Galili & Hazan, 2001; NRC 1996; VanSledright & Frankes, 1998). Yet, using HPS materials in physics education "is perceived as feasible and desirable, worthy of investing expanded effort and resources" (Galili & Hazan, 2001).

It is the purpose of this paper to examine the effects on student attitudes toward the nature of science and on student understanding of Newtonian principles that result from students being taught the traditional concepts of physics within a context of the history and philosophy of physics, using primary sources, in a general, introductory high school physics class.

Literature review: Benefits of history and philosophy

A survey of the literature related to this issue shows that while the idea of teaching introductory physics through a context of history and philosophy of physics dates back to at least the 19th century, and has been advocated at various times over the decades since (Galili & Hazan, 2001; Matthews, 1989a; Matthews, 1989b), it has not often been the subject of formal research (NRC, 1996).

One of the few attempts to greatly involve history and philosophy of science in a published curriculum and textbook was the Project Physics Course used primarily in the 1970s (Brush, 1989). This course's text did "not simply present the conclusions of research but shows how they were obtained" (ibid, p. 61). Research on students who took this course suggests that students' attitudes toward physics were changed—students found the course "less difficult and mathematical, and the text was more enjoyable to read" than a contemporaneous, logically-based curriculum (ibid, p. 62). Students also did "nearly as well" on standardized physics tests as students who took other courses, and Brush notes that the slightly lower performance of these Project Physics students may be partly explained by the possibility that "students with low interest or ability in science" may have been steered by their schools toward the Project Physics course. Such research may not apply to other curricula using history of science, of course, but Brush judges that “we now have enough concrete evidence showing that the historical approach does have an impact on students, without interfering with their learning of the technical content of science, to proceed further in implementing such proposals” (ibid, p. 66).

Alternative methods of teaching physics are not unwarranted. Current methods, which are frequently the “logical” approach, not only deter students from taking physics classes, the methods often fail to really affect the beliefs about the physical world of students who do finish the class. Students often just memorize, rather than deeply, intuitively understand, the material for the class tests (Hestenes et al., 1992; Matthews, 1989). Matthews adds, “Many others have remarked on this failure of science teaching to disturb ingrained beliefs. Students often live in two worlds, one for the science exam, another for everyday life. This is alarmingly illustrated in recent American surveys showing that belief in astrology is very little affected by completion of an American science degree” (1989, p. 9).

As physics educators look for alternatives, one that is frequently mentioned is the inclusion of the history and philosophy of science in introductory science classes. HPS study does have the support of at least some experts in physics education. Galili and Hazan surveyed a group of 12 Israeli physicists, physics educators, and historians and philosophers of physics on their attitudes toward and ideas about the role of history and philosophy of science in physics education. This approach was “perceived as feasible and desirable, worth of investing expanded effort and resources” (2001).

The positive impacts given by the experts in the literature justify using this approach, and these can be explicated and summarized in four main areas: first, that HPS increases achievement in traditional physics learning; second, that HPS gives students a more factual, realistic idea of science's development; third, that an HPS approach shows the relationship between science and other intellectual culture; and fourth, that an HPS approach can increase student appreciation of and enjoyment in science courses.

First, that studying the traditional concepts and theories of physics from within a historical and philosophical context helps students learn those traditional concepts better.

Beyond the research on Project Physics mentioned above, there seems to be little research in how historical context affects student scores on standardized physics tests. This may be in part because student development of deep understanding of nature of science issues (as opposed to trivial knowledge, such as names and dates of scientific developments), are difficult to test objectively, instead often being assessed through essays and other assignments (Gooday, 2000; Kauffman, 1989).

However, it is suggested in the literature that presenting the traditional concepts through their historical development makes the traditional concepts easier for students to understand (NRC, 1996).

One way to explain this is through the notion that "ontogeny recapitulates phylogeny," the idea that students go through the same order of concept development as they learn science that the civilization at large went through in creating those concepts (Galili & Hazan, 2001; G. Matthews, 1980, p. 72; M. Matthews, 1989a).

Another idea supporting this approach is that studying philosophy conditions students to receive and mentally process the concepts in physics, which are essentially philosophical in nature. The ideas studied in physics—such as force, velocity, and work—are abstract and philosophical in nature, especially in comparison to the concepts in biology and chemistry classes students have previously taken, and understanding this takes a unique epistemological background. While some research shows that even high school juniors have simplistic ideas about the epistemology of science, research also suggests that even sixth grade students are capable of forming more-sophisticated epistemological thoughts as long as these children are taught science in a context that explicitly deals with the nature of science (Smith et al., 2000). To extrapolate a bit, it seems reasonable to say that after students are exposed to abstract, philosophical ideas, they are better able to understand them in the future. Such could be the case with the abstract central concepts in physics.

Matthews (1989a, p. 11) asserts that

> philosophy enhances classroom teaching. A simple lesson on mechanics can be transformed if questions are raised about the relationship of theories to evidence, about what is required of a good experiment, or who for example we define acceleration as change of velocity with respect to time rather than distance. … historical and philosophical perspectives can be developed, and they can contribute to the better and more interesting teaching of science.

These familiar concepts that are traditionally taught in physics classes *are essentially* philosophical in nature. All too often, this is brushed aside in science textbooks and classes. Science instructor Brackenridge writes "my challenge as an instructor is, on the one hand, to persuade students in the sciences that contemporary scientific concepts, such as space, time, void, motion, and so on, are not 'obvious' and that their understanding and appreciation of them is enhanced by knowing how they have evolved and are even now evolving" (1989, p. 79). For students to see these concepts *as inherently* philosophical, and not merely technical, can aid their understanding of them.

Winchester points out that the revolutionary "heroes" of science were doing philosophy when they were creating a new frameworks, or new perspectives, on the already existing evidence (1989, p. iii). He writes:

> Philosophy of science is in large part concerned with the study of the conceptual problems engendered by scientific notions. It is arguable that what Newton, Einstein, and Darwin were primarily engaging in was philosophical activity of this kind when they were reshaping the central concepts in their respective sciences. Such work as theirs, if new generations are to aspire to emulate it, requires not only an intimate sense of the empirical but also an intimate sense of the conceptual which can be had only by a thorough grasp of the historical development of their special science. Thus the historical and philosophical in science are centrally related—and arguably centrally related to any advance in any scientific discipline.

Cushing points out that while many rank-and-file physicists express little interest in the philosophy of their discipline, those whose work revolutionized and reformulated the discipline – including Newton, Planck, Einstein, Schrodinger, and Bohr – were interested in the philosophical issues of physics (1989).

Not only scientists themselves are using philosophy, but Matthews argues philosophical issues arise frequently in science education. "In science education the effects of philosophical understandings or misunderstandings are everywhere apparent—from statements of putative scientific method, to accounts of scientific law, to opinions about the structure of science" (1989a, p. 10). Brush (1989) says philosophical issues are often ignored in physics textbooks, but that the philosophy can be dealt with though a history-of-science approach. "Science deals with broad philosophical questions that should be of general interest even though they are often ignored in textbooks. These questions are best discussed in their historical settings" (p. 63).

Students taught in HPS context may also be better at thinking not merely within the discipline, but *about* the discipline, metacognitively. As Brush puts it, "while the logical approach may train a scientist to solve specified problems more efficiently, the historical approach would help him decide for himself what problems are worth trying to solve" (1969, p. 273). Kauffman quotes a fellow science educator as saying "while it is possible to *train a chemical technologist* without giving him a knowledge of history of chemistry, it is difficult to *educate a creative chemist* without such knowledge" (1989, p. 90) [italics in original]. This likely holds true for physicists as well as chemists.

Furthermore, students may learn from history study characteristics that make them better scientists. Physicist Ernst Mach wrote "whoever knows only one view or one form of a view does not believe that another has ever stood in its place, or that another will ever succeed it; he neither doubts nor tests" (as quoted in Matthews, 1989a).

The *second* benefit is that studying the history and philosophy of physics provides students with a more realistic perspective of the development of the science than does the traditional logical approach.

The AAAS Benchmarks point out the problem that an in-depth study of history can fix:

> The images that many people have of science and how it works are often distorted. The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, the study of science as a way of knowing needs to be made explicit in the curriculum. (1993)

Brouwer and Singh detail some of these myths and stereotypes:

> Science is often viewed by nonscientists as a cold, neutral, very successful, objectively verified area of knowledge. The view of the 'tentative nature of scientific knowledge,' the presence of alternative interpretations of scientific theories, the dependence of a period's scientific knowledge upon the basic 'world view' held by scientists of that period is often insufficiently stressed in science courses. (1983, p. 231)

Most textbooks do not really discuss history per se; instead they confine their history to "names and dates" of the great scientists, which gives the book a "superficially historical appearance" (Brush, 1969). When issues are discussed in any greater depth in textbooks, the history is often portrayed from the modern perspective of the understanding of science, rather than setting the historical issues in the contexts of their times (Brackenridge, 1989; Kauffman, 1989). This is often called a "'Whig'" interpretation of history," "a particularly insidious type of distortion that views historical events not in the true perspective of their time but rather in the light of how they contributed to the present state of science today…. It is all too easy to judge past events in terms of present values and to regard any theories that did not lead to our present theories as 'wrong.'" (Kauffman, 1989, p. 86-87).

Other "myths and stereotypes" students have are likely not challenged by, if not reinforced by, the traditional, logical science classes students have in high school. For example, in science classes students are expected to learn the established theory and arrive at "right" answers—there's little student creativity involved. However, the practices of scientists often require many similar creative skills to those used by artists and others in humanities (Winchester, 1985; Kauffman, 1989). Brouwer and Singh write “students are not sufficiently exposed to the imaginative, creative processes by which a scientific model is first constructed, or the flashes of insight by which theories are born, or by which solutions to difficult problems are first recognized” (1983, p. 231).

Another myth perpetrated by many textbooks is that there is one “scientific method” which uses a very clear set of steps to lead to the solving of a physical question. Experts say this is a myth because there is no single scientific method that is employed by every scientist to make every scientific discovery (Brush, 1969; Kauffman, 1989; Koul & Dana, 1997). Not only is there no single method, but as science historical Holton points out, there is often in the history of science “apparent contradiction” between the “’illogical’ nature of actual discovery and the logical nature of well-developed physical concepts” (quoted by Kauffman, 1989, p. 88). Thus, integrating the history of science into a science course “places the nature of discoveries in a truer perspective. They are then seen not by the student as isolated and completely independent events created by great men” (ibid, p. 83).

Nor are all scientists motivated only by a search for Truth. Brouwer and Singh point to historical research suggesting scientists have been “often motivated by social, technological, or economic concerns,” and they cite Kuhn as revealing that the science community’s acceptance or rejection of new theories involves a “faith commitment” that goes beyond merely rational considerations (1983, p. 231).

Nor is the science endeavor always one of progress, as Kauffman suggests: “The history of science, in common with all history, is not a smooth, continuous function, but rather a messy chaotic one that proceeds in forward ‘spurts’ and occasionally leads to dead ends or even backward steps” (ibid, p. 87). He adds that discoveries are often the result of inter-related events and of many people rather than just a sole person single-handedly making discoveries (1989). The use of theories that were once accepted but have been discarded is another way of showing "a more realistic picture of how science actually progresses than does a course in which only successful ideas are presented" (ibid, p. 87).

Of course, there is no one definitive history of science, either. Matthews writes, "clearly there is no single 'history of science,' and it is a mistake to pretend that there is" (1989a, p. 9), and yet that's not an insurmountable obstacle. It merely represents a chance to get students engaged and thinking by bringing up questions. In Matthews' words, "teachers teach best when they provide not answers but questions that engage and stimulate the student" (ibid).

All too often, it is not the questions but the answers that are valued in science classes. A common danger of the traditionally taught physics course is that it can be too easy to focus on formulas and solving problems, which reduces the physics class to an "applied math" class. Brouwer and Singh point out that a historical focus can put the formulas of physics into perspective:

"An emphasis on the historical development of scientific ideas *can* help to keep alive the question: But what is *really* going on here? And we will surprise ourselves in recognizing that science often does not (yet) understand 'What is really going here?' [sic] With occasional discussions on the basic 'nature of things' the mathematical description of reality easily assumes its rightful subordinate place in the development of our understanding" (Brouwer and Singh, 1983, p. 235). [italics in original]

The *third* benefit to studying physics within a context of HPS is that it enables students to see the connections between and mutual influence of science and other disciplines, as well as the role of science in the culture at large (Cushing, 1989; Galili & Hazan, 2001; Kauffman, 1989;

Parisi, 1985; Winchester, 1985). Understanding this point is vital for science literacy (AAAS, 1993).

Cushing (1989) explains:

> Instruction with some historically meaningful dimension will bring across nicely the dramatic changes in world views which have always accompanied advances in science: Aristotelian to Newtonian-mechanistic to indeterministic-quantum. The locus of such revolutionary change will be seen not to be isolated in the distant historical past but to be a dramatic part of the current scientific enterprise as well. On the one hand, this can help to produce a knowledgeable group of lay citizens who possess some understanding of the principles of science and a realistic image of the construction of scientific knowledge. On the other hand, it can help to form a corps of young scientists who appreciate that science has profound philosophical implications for man's view of his world and that the generation of scientific knowledge has important similarities with corresponding activities in other fields. A gap between the 'two cultures' results more from mutual ignorance than from any objectively existing difference in methods employed in and in absolute certainty obtainable by the 'sciences' versus the 'arts'. An appreciation of this fact may be the most important general lesson to be gotten across to students by a new approach to science instruction. (p. 58)

AAAS also suggests that being scientifically literate is vital for citizens to make good decisions on current issues involving science (ibid). Koul and Dana argue science ought to be taught within a context that recognizes citizens' involvement in political and economic issues (1997). Winchester agrees, and points out the role history of science can play in preparing students to be citizens.

> In a democratic society many possible views of science and its relation to modern technology and to modern technological civilization might be held. If the schools are to support such a democratic society, then science must, it seems, be taught in such a way that it is seen 'warts and all.' And only the history of science can offer that –through not, of course, the potted history of science of the textbooks but rather the genuine activity which includes the social history of science and its relation to both past and contemporary civilization and culture. (1989, p. v)

Carson agrees that science did not develop "independent of the other disciplines. It is one dimension of a complex culture" (1997, p. 109). That is to say, it cannot be completely understood outside of or apart from the broad milieu of intellectual culture. As such, "science educators … are wrong-headed in discussing science education as if it were an end in itself. My suggestion is that the central goal is not to teach science—the goal is to teach *about* science and about scientific culture, and within that larger framework, then, to teach science itself"[emphasis in original] (ibid, p. 115).

This is important because the scientific knowledge and the scientific perspective have become incorporated into the world view of those who have been brought up within Western civilization. Carson argues that science is relevant not "primarily from the things it enables us to do, but from the manner in which it has constituted the mind of everyone in our society. In that sense, it is part of the explanation of who we are" (1997, p. 115).

Further, who we are is a people who base and construct most of our beliefs within a logical, evidentiary (that is, scientific) way of knowing. Carson asserts it is the role of a science class to make this way of knowing, this epistemology, explicit to students. It's more important to teach students this aspect of the philosophy of science than it is the particular theories within science.

> Ours is a culture whose universal claim to prestige is its highly refined capacity to defend its conclusions; yet we expect students to intuit the validity of these conclusions merely from the degree of confidence we have in them, or from a few paltry demonstrations, and so to accept our ideas as authoritative. We show them proofs, but we seldom lay an adequate groundwork to persuade them that this approach to truth-finding and truth-telling is any better than common sense and intuition. All the while, we tell them to be critical thinkers, and we assure them that a *scientific method* underlies the conclusions we have reached. It took thousands of years to develop that method. It also takes time to develop in individuals. (Carson, 1997, p. 118) [italics in original]

Carson argues that all the disciplines taught in schools should be taught within a philosophical framework, or "metanarrative," to overcome the disciplinary fragmentation common to most schools' structures (ibid, p. 110). Not only will this approach broaden students' understanding, it will make science more attractive to students.

"If we want to create a real interest in science, we need more than just facts and demonstrations, or the subtle techniques of indoctrination and psychological bullying that constitute the latest advances in science education. We need to tell the story – why people have loved this discipline, as well as why others have hated it. We need to embed this story into the larger story of humankind, and show the rise of scientific culture against the backdrop of those far more ubiquitous and durable cultures that are grounded in traditional ways" (Carson, 1997, p. 117).

This leads to the *fourth* main advantage given in the literature of teaching physics within a framework of history and philosophy of science, which is that studying HPS increases students' overall appreciation for and enjoyment of science.

This is particularly important when physics teachers have seen, for decades, declining enrollment in physics (Brush, 1969; Matthews, 1989a). Brush and Matthews view an HPS approach to teaching physics as one way to rebuild student interest in physics, especially among students who are less interested in the mathematical aspects of physics (ibid), or in the "impersonal, wholly rational, and logical approach" emphasized by science textbooks (Kauffman, 1989, p. 82).

Some science teachers may say that the formulas and the rationality are "what science is," but a survey of the history of science, as outlined above, shows that to not be the case. What interested a lot of scientists in physics are the broader philosophical aspects of the discipline. This may also attract students' interest. Brouwer and Singh explain it this way:

> Scientists and science teachers have often stopped asking questions about the 'reality of things' since it is so much easier to agree as a community on, and to teach, the mathematical description of things. Yet we pay a terrible price; we reduce to mathematical equations those very things that excite our wonder about nature in the first place (1983, p. 235).

Carson goes further, saying an HPS approach is essential, for without it, the purpose of learning physics becomes vague. "In the absence of this broader cultural perspective, science education has little option but to be a dogmatic vocational inculcation, or worse, a bewildering pedagogical exercise, too abstract and esoteric to be of much interest to most students" (1997, p. 115).

Matthews also recommends using the interest inherent in the HPS approach to physics:

> There is no subject matter that cannot be made more interesting and engaging the by the introduction of philosophical considerations, be they world view considerations or technical, analytic ones. The object is not to teach the philosophy, but to enhance the learning and to promote a greater awareness of the intellectual excitement and achievement of science; to see it as a cultural activity that informs other areas of life (religion, ethics, philosophy) and is in turn informed and influenced by them; to begin to understand how, and in what sense, science gives us the best understanding we have the of world we live in (1989, p. 12).

“The full flavor and excitement of science as a creative process cannot be experienced in a historical and philosophical vacuum,” writes Brackenridge (1989, p. 80).

Another benefit of teaching students how science has developed is that it allows students to see backstage, to see the scientific people “behind the curtain,” as it were, and to see that scientists throughout history have struggled with the same concepts the students may be currently struggling with. As Brouwer and Singh write, “it would build students’ self-confidence to realize that such questions are not naïve or stupid but relate to very fundamental ideas about our current understanding of nature” (1983, p. 232).

Students may come to feel more empowered, more confident, in their own ability to think scientifically and to question scientific ideas when they learn an accurate history of science. When students are faced with textbooks that “claim authority and truth” (Martin and Brouwer, 1991), it may be psychologically hard for them to question these claims. The set of physics ideas seems monolithic – where does one start learning, let alone start questioning? But when students “view the great men and women of science not as intellectual giants but as human beings with human strengths, and weaknesses similar to his [the student's] own" (Kauffman, 1989, p. 84). then students may begin to feel that they to can ask these fundamental questions and they can trust themselves to work through an answer for themselves – and this could be the seed that develops into a real scientific perspective.

Literature review: Potential difficulties

The literature does mention some potential difficulties with the HPS approach to teaching physics. However, these difficulties are "not absolute disadvantages but merely caveats" (Kauffman, 1989, p. 84).

The objection mentioned most often is that the physics curriculum is already overstuffed with topics, and including a historical perspective will force these classes to cover less (Arons, 1997; Brush 1969; Galili & Hazan, 2001; Kauffman, 1989; Winchester, 1989). But most experts who raise this point follow it by saying this is not in itself a big enough obstacle to avoid the historical approach. Arons (1997) says the curriculum of the introductory physics course is already too full, and that paring it down would allow more time for students to develop deeper understanding of the most-important topics.

AAAS also thinks most science curricula are "overstuffed":

> "If we want students to learn science, mathematics, and technology well, we must radically reduce the sheer amount of material now being covered. The overstuffed curriculum places a premium on the ability to commit terms, algorithms, and generalizations to short-term memory and impedes the acquisition of understanding (1993).

In addition, covering fewer subjects more deeply may lead to better real understanding by students. Winchester cites Whitehead's admonition that avoiding "mental dryrot" requires not teaching “too many subjects,” and “what you teach, teach thoroughly” (Whitehead, 1929, p. 2; Winchester, 1989).

Kauffman also points out that history and science have different disciplinary approaches: where science starts with detail and then it generalizes from that detail, history starts abstract and focuses in on particular details. But he writes that this is not an obstacle but merely an aspect of historical study that should be pointed out to students (1989).

Experts also warn teachers against oversimplifying history and turning it into the “Whig” history described above (Kauffman, 1989; Matthews, 1989a).

Others suggest teachers may not be prepared to teach historical and/or philosophical issues in science classes (Brush, 1969; Brush, 1989; Matthews, 2001; Winchester, 1989).

Physicists, but not other physics education experts, presented arguments against using HPS in regular science classes in the survey by Galili and Hazan (2001). In addition to concerns about the additional class time required for the HPS study, they mentioned that students might have difficulty understanding the contexts of the scientists who come from other cultures and centuries. For example, they say students might be put off by the religious motivation of some scientists. Yet, to exclude certain facts because they make the investigator uncomfortable does not seem like a good reason.

Another difficulty is assessing student work in history and philosophy of science (Garver, 2001; Galili & Hazan, 2001; Gooday, 2000; Kauffman, 1989). Gooday in particular points out that university students familiar with the nature of homework in traditional science classes (solving problems, trusting the authority of the textbook, getting the “right” answer from instructors) may have a difficult time figuring out precisely what constitutes good work in history or philosophy (in which students construct their own arguments, they use multiple texts, none of which has absolute authority, and the student is expected to come up with original arguments rather than merely repeating the instructors') (2000). However, Gooday suggests that showing students precisely what differentiates good work from lesser work will help students be successful across disciplinary boundaries.

And as Brush (1969) points out, if teachers do not teach HPS, they are in essence ignoring the high value placed on factual accuracy in the scientific discipline. "Do we really want to suppress in this way the facts about how scientific theories have developed?" (p. 277)

Literature review: Primary sources

With the benefits of teaching HPS established in the literature, the question now arises of what methods should be used to teach HPS.

The literature offers many suggestions of ways to teach the history and philosophy of science. Looking at case studies, performing historical experiments, and other approaches are given (Brush, 1969; Galili & Hazan, 2001).

The method that will be selected in this research proposal is using original or primary sources in the science class. By this I mean mainly the published works of the scientists themselves, as opposed to interpretations of these (secondary sources) or textbooks. This particular method to teaching HPS is mentioned or recommended by several experts (Brush, 1969; Cushing, 1989; Galili & Hazan, 2001; Kauffman, 1989), and it is not a new idea – Matthews reports a headmaster advising students to read scientists' original writings in the 1920s (1989a and 1989b). As experts point out, using original sources is common in the humanities but it has not been common in science (Brackenridge, 1989; Kauffman, 1989), and so if the goal of a science class is to show commonalities among the disciplines, as discussed above, primary sources would seem to support that goal.

VanSledright and Frankes note that they found very few research studies on the use of any kinds of literature in high school science classrooms. However, they do quote a study by Perfetti et al that used multiple texts in a college history class in which Perfetti et al. concluded:

> simply that there is value in multiple text learning. It allows students a richer representation of the situation to be learned. It forces an awareness of texts, as opposed to situations, and it can be structured so as to focus on thinking and problem solving. History seems to be an ideal subject around which to promote the use of multiple texts and documents—and from which to develop text-based reasoning skills (quoted in VanSledright and Frankes, 1998, p. 135).

Extrapolating from this, there may be value to a high school physics class studying history of science to use texts as well.

The literature lists many other reasons to support this primary-source approach.

One is that using original sources directly and indirectly supports the teaching of the nature of science in a physics course. A physics education expert interviewed by Galili and Hazan (2001) gave this benefit:

> Original scientific texts will represent authentic research in real science, and demonstrate conceptual changes as described in these texts. To attain such effect, instructors should carefully chose [sic] documents which will illustrate the relevant changes in the considered scientific conception, and which can be appreciated by students.

As Brush points out, teachers may need to resort to primary sources if for no other reason that secondary sources frequently “perpetuate historical myths” (1969, p.275). He writes, “what is really valuable in an historical approach is a detailed account of the intellectual and personal factors which go into the making of a scientific discovery, and this can rarely be obtained without careful and time-consuming research based on primary sources" (1969, p. 278).

Cushing writes that, particularly in some topics, classic texts and papers of science "often have more clarity than treatments in some modern textbooks. Classic texts also give the student some sense of the history of discovery in science" (1989, p. 57).

Brackenridge argues it is valuable to study original writings of early scientists to see where and how textbooks distort history. His analysis showed "Galileo himself was guilty of writing history backwards" (p. 77), as are modern textbook authors. "Claims concerning Newton's analysis and procedures in the *Principia* abound in the modern textbook, but they bear little resemblance to the actual content of that work" (p. 78).

The literature also contains some potential difficulties with using primary sources in the physics classroom. For one, even in modern translation, these sources are "difficult to read and to understand" (Brackenridge, 1989, p. 78). Students may need a lot of preparation before they can make use of these texts, and teachers would have to invest a lot of work in gathering these materials (Galili & Hazan, 2001). Another issue is that while these sources are the product of the individual scientists, these are the public, formalized representation of these ideas – these sources do not necessarily show the exact way the ideas were developed, which is very hard to do (Brush, 1969; Brouwer and Singh, 1983).

Methodology: Question

After reviewing this literature, the question arose, What would be the effects of teaching an introductory physics class within the context of history and philosophy of science (HPS) using primary sources?

Methodology: Subjects

This research plan will use the students in introductory physics classes at Rochelle Township High School. These students will be juniors or seniors. Entering this class, they have likely taken two or three years of science, including chemistry and biology, but these classes are taught traditionally, logically, and little emphasis is given to either the history or philosophy of science. As a prerequisite for this class, students must have completed the second year of algebra.

Students are self-selected for this class, although many are encouraged to take it by their counselor or their parents. Judging by previous physics classes, most physics students are college-bound, and a significant proportion, perhaps 40 percent, will take additional physics courses at the college level, while the remainder of students will not study a scientific or technical discipline. Physics classes during the fall of 2004 will have about 20 students in each of two sections.

To protect student interests, a letter describing this research project will be sent to parents of the students in these classes, and parents will have to give their written consent for their students to be involved in this project. (see Appendix A)

Methodology: Instruments

This research project will product both quantitative data about student achievement with physics concepts and quantitative and qualitative data about student attitudes toward and beliefs about science.

The effects of this teaching method will be examined three ways: through a science attitude survey, administered before and after the unit is taught; a criterion-referenced test of Newtonian force concepts, administered at the end of the unit, and student journals written throughout the unit.

The attitude survey to be used will be Scientific Attitude Inventory or SAI II (Moore & Foy, 1997). This is a survey instrument that seeks to examine student attitudes about both the nature of science and students' own feelings toward science. (See Appendix C)

This instrument consists of 40 questions based around six "position statements." (ibid, p. 333). Students rank their responses on a scale of 1 to 5 for each question, where 1 indicates strong disagreement, 3 means neutrality, and 5 signifies strong agreement with the question asked.

While this instrument's "conceptual validity" has been questioned (Munby, 1997), this instrument has been widely used in scientific research since the creation of the original SAI more than 30 years ago, and according to its authors it continues to be used (Moore & Foy, 1997). The authors explain that the instruments' validity is based on "a statistically significant difference was obtained for each t-test comparison" (ibid, p. 327) and that face validity is claimed based on the resemblance of this instrument to a previous version, whose validity is asserted based on its method of construction. However, authors report that factor analysis did not lend validity support. The SAI II was field tested on nearly 600 students in 6^{th}, 9^{th}, and 12^{th} grades (ibid).

This instrument will be given as a pre-test, before any instruction, and then it will also be administered at the end of the unit as well, to allow for comparison of scores for each particular student.

The second instrument will be used to assess students' learning of Newtonian force concepts. The instrument, the Force Concept Inventory, consists of 29 multiple choice questions, and responses are keyed to particular concepts (Hestenes, Wells, & Swackhamer, 1992). (See Appendix D). This instrument has been given to more than 1,500 high school physics students and more than 500 university physics students (ibid). Comparison scores of test takers is provided for comparison. A scoring of 80% correct is judged to be a "threshold score for Newtonian thinkers" (ibid, p. 146). It is mentioned that giving this instrument as a pretest is not useful, for it measures not aptitude for physics but the student's level of accomplishment in learning specific, standard-physics ideas. No correlation of scores to socioeconomic level exists (ibid). The instrument also does not significantly reveal differences between teachers when teachers are using similar "conventional instruction" methods, so the instrument is judged to measure the effects of different instructional methods on student performance (ibid). This is precisely what the proposal hopes to measure. This instrument will be administered only at the end of the instruction.

Lastly, student attitudes and beliefs will be collected qualitatively from student journaling throughout the unit. Students will be instructed to write a few sentences about their particular beliefs, their own understandings of the nature of science, and so on. These will be evaluated informally by the teacher and used for ongoing feedback and as evidence of student progress for parent conferences.

Methodology: Procedures

Keeping in mind Kauffman's advice that teachers can begin HPS teaching without revising the entire curriculum (1989), this research will comprise one unit of this physics course – the introductory unit to Newtonian forces. This unit will require about six weeks of classroom time (50-minute periods, five days each week) during the fall semester, 2004, and in will begin the semester.

The unit will focus on reading two sections from Newton's seminal work of physics, the Principia (1999). However, in order to make sense of this book, students will begin at the beginning of scientific thought in Western civilization, with the philosophical speculations of the

Greeks. Then students will be taught, through lecture and text reading, about Newton's predecessors and contemporaries, to establish some context for Newton's project. This is a difficult book to read, even in modern translation, and so reading will likely be done in class, modeled and supported by the instructor. Newton's own physical examples will be re-created and examined, and students will also apply their new understandings of Newton's ideas to novel physical situations. Finally, because students still need to learn how to solve physics problems if they later take a traditionally taught class, students will be instructed in solving problems using force concepts in a modern textbook (Hecht). See Appendix B for a more specific listing of instructional plans.

Methodology: Data analysis

Data from the pre-instruction and post-instruction SAI II attitude assessments will be averaged for the entire group of students, and examined for signs of change. Standard deviations will be looked at to see how tightly grouped student attitudes are. A significance test such as the Pearson test will be administered to the data to see if attitude numbers correlate with the instruction under trial.

Data from the Force Concept Inventory will be keyed to the criterion-key provided with the instrument, and note will be made of any particular concept missed by a large number of students. An accounting of students meeting the competency score of 80% will be made, and averaged student scores will be compared to the data for other students given with the instrument (Hestenes, Wells, & Swackhamer, 1992).

Student journals will be reviewed by the instructor to see how particular students' attitudes and beliefs change through the duration of this research.

After collecting this data, any trends or deficiencies spotted in student data will be addressed in future research trials.

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Appendix A

Permission letter

Dear Parent of a Rochelle Township High School physics student:

With your permission, this fall 2004 semester your student will be participating in a research study examining an alternative methodology of teaching physics. This research process will require students to take a small number of assessments simply for purposes of evaluating the teaching methods. With your signed permission below, your student will receive the alternative methodology and your student will commit to completing the assessments.

Sincerely,

Matt Hagemann
Physics instructor

My child ___________________ has permission to be a student in a research study of alternative methodologies for teaching physics.

Signed ________________ Please print name ______________ Date _________________

APPENDIX B
Instruction Specifics

Discussions will include the following questions:

(the purpose is to introduce students to the nature and purpose of philosophical thinking)

-- Early discussions

-- How do we know anything?

-- What is real or reality? What really exists?

-- How does science relate to reality?

-- Later discussions

-- On particular texts or scientific thinkers:

How does this person's thinking match with others'?

What is new in this person's thinking?

-- How does this text match with the current understanding?

(as given in the Hecht (2003) or Zitzewitz (1995) textbooks)

Text readings will include:

Primary sources:

-- "Definitions" and the "Axioms, or the Laws of Motion" sections of Principia (Newton, 1999, p.403-430).

-- Selections from "Concerning the Two New Sciences" by Galileo (1952, p.129-266)

Secondary (context-setting) sources

For Newton

-- "Newton's Laws and His System of the World" (Holton & Brush, 2001, p. 103-122)

-- The chapter on the Principia from "The Classics of Science" (Gjertsen, 1984, p. 187-220)

For philosophy of science –

Selections from "The Presocratic Philosophers." (Barnes, 1979)

Demonstrations and laboratory exercises will include:

-- Newton's example of water in a spinning bucket

-- Newton's example of forces on a wheel

-- Determination of forces in a tug-of-war

Problem assignments:

-- Assorted problems on pages 128-140 in "Newton's Three Laws" chapter in Hecht (2003)

-- Assorted problems on pages 163-170 in "Centripetal Force & Gravity" chapter in Hecht (ibid)