Title
Physics First in Science Education Reform: Impacts on Pedagogy

Author
Purnell, Mechum Douglas

Publication Date
2012

UNIVERSITY OF CALIFORNIA

Los Angeles

Physics First in Science Education Reform: Impacts on Pedagogy

A dissertation submitted in partial satisfaction of the requirements for the degree

Doctor of Education

by

Mechum Douglas Purnell

2012

ABSTRACT OF THE DISSERATION

Physics First in Science Education Reform: Impacts on Pedagogy

Mechum Douglas Purnell

Doctor of Education

University of California, Los Angeles, 2012

Professor William A. Sandoval, Chair

This paper presents the results of a study focused on physics and chemistry teachers at independent schools in the United States which employ a "Physics First" approach to high school science course sequencing. Data was collected via interviews, during which information was gathered regarding pedagogical practices and teachers' transitions to Physics First. Findings suggest that the implementation of inquiry-oriented pedagogy is influenced by teacher and department philosophy, but not necessarily by the Physics First approach. Further, teachers recognize the affordances of Physics First, but largely do not leverage these to create more coherent and connected science programs.

The dissertation of Mechum Douglas Purnell is approved.

Noel D. Enyedy

Linda J. Sax

James W. Stigler

William A. Sandoval, Committee Chair

University of California, Los Angeles

2012

Dedication

This project is dedicated to teachers around the world who refuse to do it the same old way.

Table of Contents

List of Tables

Acknowledgements

I would like thank to everyone who helped me in this project, large and small. Without the twenty wonderful teachers who gave up their time to talk to me, there would not have been a study. Thanks in particular to Bill Sandoval and my committee for their guidance and especially for their willingness to work with me through what has been a very challenging timeline. Friends and family have been a rock-solid base for me. In particular, I am now and forever indebted to Lacey Giles, my best friend, partner in crime, and more thoughtful third. Without her constant support and positivity, I would not be who or where I am today.

VITA

2007	M.Ed. International Education Framingham State University Framingham, Massachusetts
2000	B.A. Physics College of Charleston Charleston, South Carolina
2007-2012	Physics Teacher, Class Dean Brentwood School Los Angeles, California
2005-2007	AP Physics Teacher Seoul International School Seoul, South Korea
2003-2005	AP Physics, AP Chemistry Teacher American Cooperative School of La Paz La Paz, Bolivia
2000-2003	Physics, Chemistry Teacher Thai-Chinese International School Bangkok, Thailand

Chapter 1 - Introduction

International science assessments show that students in the United States lag behind their developed-nations counterparts (National Center on Education and the Economy, US Department of Education, 2011; National Center for Education Statistics, US Department of Education, 2008, 2007a). At issue are outmoded pedagogical approaches and incoherent science education programs delivered to students in this country. A restructuring of high school science, involving both curricular and pedagogical transformations, is warranted. Proponents suggest that the Physics First approach to high school science, which inverts the traditional sequence of disciplines, may positively impact science education programs. The primary goal of this study is to better understand the impacts of the Physics First approach on pedagogy and program coherence at the high school level.

Science education reform literature broadly recommends two changes to the way science is taught in the United States. The first of these changes is to emphasize inquiry-oriented activities in science (Schroeder, Scott, Tolson, Huang, & Lee, 2007), and the other is to enhance the coherence of science programs (Schmidt et al., 2011). The traditional approach to science course sequencing in the United States is biology-chemistry-physics (Neuschatz, McFarling, & White, 2008). The hallmark change in Physics First is the reversal of this sequence to physics-chemistry-biology. Because the revised sequence recognizes the embedded hierarchical nature these fields of science, it is suggested that students and teachers may forge stronger and more meaningful curricular and cognitive connections between successive courses. Furthermore, Physics First proponents argue that the macroscopic, readily-tangible phenomena typical of introductory physics are uniquely well-suited to inquiry-oriented instructional models, making physics a natural choice for the emphasis of this style of pedagogy in ninth grade (American Association of Physics Teachers, 2006).

While it is difficult to pinpoint the specific effect of Physics First on broad measures of the effectiveness of science education, this study will investigate the extent to which schools employing Physics First demonstrate inquiry-oriented pedagogy and program coherence. In this way, one aim of the project is to make a statement about the viability of Physics First as a science education reform measure.

Chapter 2 - Review of Literature

Students in the United States lag behind their developed-nations counterparts on assessments of scientific literacy and on measures of academic achievement in science. These measures will be thoroughly examined, and science education reform literature will be scrutinized for recommendations. Two proposed changes to the way science is taught will be investigated: the first, to emphasize inquiry-oriented activities in science, the second is to enhance the coherence of instructional programs. These changes may be accomplished via Physics First; the manner in which this may impact pedagogy and program coherence is discussed in detail.

High School Science Education in the United States

How do we know there is a problem with science education in the United States? By all broad metrics (e.g. TIMSS, PISA, NAEP - discussed later), US science education has produced consistently mediocre results over the last twenty years (Schmidt et al., 2011). The two key indicators discussed here are academic achievement in science and science literacy. These highlight outcomes of the current science education system in both broad and narrow terms. Science literacy refers to an individual's ability to employ scientific modes of thinking, even in contexts that are not specifically related to what may be considered "academic" science (National Research Council, 1996). Student achievement rates in precisely those academic contexts of science knowledge, including STEM enrollment rates in higher education, present a more focused picture of the effectiveness of the country's science education system.

Science literacy

A multifaceted concept, science literacy refers to an individual's ability to use scientific knowledge and modes of analyzing information to make informed decisions. Scientifically literate people display their literacy by expressing positions that are scientifically and technologically informed (National Research Council, 1996).

Two research organizations, the National Research Council and the American Association for the Advancement of Science, figure prominently in science education and science education reform literature. The National Research Council (NRC) is one part of the National Academies of Science, its mission is to provide elected leaders, policy makers, and the public with expert advice based on sound scientific research. Their publication, the National Science Education Standards (1996), is a foundational text in modern science education reform, and argues that to succeed, people must be able to learn, reason, think creatively, make decisions, and solve problems. A meaningful understanding of the scientific approach to understanding, in addition to science content knowledge, contributes to these skills. The American Association for the Advancement of Science (AAAS) is responsible for the widely-read journal *Science* and three foundational texts on modern science education reform: Science for All Americans (1990), Blueprints for Reform (1998), and Designs for Science Literacy (2001). In these texts, AAAS make a case that extensive and fundamental reform – predicated on the development of science literacy – is needed to ensure that students are prepared for life in the twenty-first century.

Others have identified that the economic productivity of the United States is increasingly linked to the science literacy of the work force; in addressing the global economic competitiveness of the United States, the importance of science and mathematics education is routinely stressed (National Center on Education and the Economy, US Department of

Education, 2006a; National Science Board, 2007). "The danger exists that Americans may not know enough about science, technology, or mathematics to contribute significantly to, or fully benefit from, the knowledge-based economy that is already taking shape around us" (Committee on Science & Engineering, National Academy of Sciences, 2007).

Science literacy metrics.

The Program for International Student Assessment (PISA) is used for the purposes of comparing the science literacy of students in the United States to those in other parts of the world. Administered every three years, PISA measures 15-year-olds' performance in reading literacy, mathematics literacy, and science literacy. First implemented in 2000, PISA is sponsored by the Organization for Economic Cooperation and Development (OECD), an intergovernmental organization of 30 relatively developed and wealthy nations. In 2006, fifty-seven countries participated in PISA, including all OECD members and 27 non-OECD jurisdictions. The PISA assessment measures student performance on a combined science literacy scale and on three science literacy subscales: identifying scientific issues, explaining phenomena scientifically, and using scientific evidence. Fifteen-year-old students in the United States had an average score of 489 on the combined science literacy scale, lower than the OECD (developed-nations) average score of 500. Students in the United States scored lower on science literacy than their peers in 16 of the other 29 OECD jurisdictions and 6 of the 27 non-OECD nations (National Center for Education Statistics, US Department of Education, 2007a). The important message of these data is that science education in the United States, for the purpose of enhancing science literacy, is found wanting when compared to the science education systems of other wealthy developed nations. It bears noting that when comparing the performance of the highest achieving students (those at the 90th percentile), there is no measurable difference between the average score of students in the United States and the OECD at large (National Center for Education Statistics, US Department of Education, 2007a). The implication of this last point is that there is a large variation in the attainment of science literacy among students in the United States; some students are clearly getting a world-class science education.

Science Achievement

Science literacy is indeed a crucial output of science education for all students, but so is academic achievement in science K-12 and subsequent enrollments in STEM programs in higher education. These indicators are more directly related to the processes by which some students go on to become scientists and engineers. The training needed to engage in the actual pursuit of new knowledge and products via scientific research is different than the ability to use scientific knowledge and understanding in one's life, the purview of science literacy. Two metrics will be discussed here, the US-only National Assessment of Educational Progress (NAEP), and the international Trends in International Science and Mathematics Study (TIMSS).

NAEP.

The NAEP measures the science knowledge and skills of fourth-, eighth-, and twelfth-grade students, who are assessed in science on the knowledge of facts, the ability to integrate this knowledge into larger constructs, and the capacity to use the tools, procedures, and reasoning processes of science to understand the world. The assessment covers Earth, physical, and life science, in the areas of conceptual understanding, scientific investigation, and practical reasoning. The NAEP is conducted every five years. In the most recent NAEP (2009), fewer than half of students qualified as "proficient" at any grade level, and no more than two percent of students at any grade performed at the "advanced" level (National Center on Education and the Economy, US Department of Education, 2011). A new assessment was employed starting in 2009, making it impossible to compare these scores to previous years. The assessment was the same, however, in 1996, 2000 and 2005. In the 2005 NAEP, the grade 12 average science score was lower than in 1996, and showed no significant change from 2000, with only 20% of students performing at “proficient” or “advanced” levels in 2005 compared to 24% in 1995 (National Center on Education and the Economy, US Department of Education, 2006b).

The implication of these data is that secondary school science in the United States is underperforming and has either stagnated or become less effective in the last fifteen years, as measured by student performance on the NAEP at least. This trend is of particular note within the context of changing course taking patterns over the last thirty years: students have graduated from high school with more science and math credits and have enrolled in more advanced science and math courses. In 1982, graduates averaged 2.2 science and 2.7 math credits. By 2004, graduates averaged 3.3 science and 3.6 math credits. In 1982, 36% of graduates had completed one or more advanced science courses, and 11% advanced math courses. These rates changed by 2004 to 69% and 33% respectively (National Center for Education Statistics, US Department of Education, 2007b). This change in course taking patterns did not translate to increased NAEP scores over that same time frame.

TIMSS.

For an international perspective, TIMSS measures the mathematics and science knowledge and skills of fourth- and eighth-graders, and is designed to align broadly with mathematics and science curricula in the participating countries, a mix of both developed and less-developed nations with diverse geographic representation (National Center for Education Statistics, US Department of Education, 2008). The 2007 TIMSS was the fourth administration since 1995. The assessment was developed and implemented by the International Association for the Evaluation of Educational Achievement, an international organization of national research institutions and governmental research agencies.

In 2007, the average science scores of both U.S. fourth-graders and eighth-graders were higher than the TIMSS average. The average U.S. fourth-grade science score was higher than those of students in 25 of the 35 other countries participating at that grade. At eighth grade, the average U.S. science score was higher than the average scores of students in 35 of the 47 other countries participating. Average scores for both U.S. fourth- and eighth-grade students in 2007 were not measurably different from those of students of the same grades in 1995 (National Center for Education Statistics, US Department of Education, 2008). Because of the diversity of the sample, it is difficult to draw broad conclusions from these data, but an implication is that U.S. fourth- and eighth-grade students perform better than international averages but on par or worse than students in other wealthy, developed nations.

STEM enrollment rates.

Enrollment rates in Science, Technology, Engineering, and Math (STEM) programs in higher education comprise the final component of the assessment of science education in the United States. This makes perhaps the most summative statement of the health of the science education system as enrollment rates determine the number of scientists a country produces itself. According to the National Science Board's *National Action Plan for Addressing the Critical Needs of the U.S. STEM Education System*, "Many high schools provide a curriculum that is uninspiring, poorly aligned, outdated, lacking in rigor, and fraught with low expectations. The net result is that almost 30 percent of high school graduates enter college unprepared for first-year coursework or arrive at the workplace without the mathematical, scientific, and technical skills that employers require" (National Science Board, 2007, p. 5). When one in three students enters college requiring remedial science and math courses, it seems reasonable that their subsequent entrance into STEM fields will be in doubt.

An argument can be advanced that two fundamental issues exist in the system: outdated methods of instruction, and incoherent programs and curricula. First, many students receive instruction that is itself outdated and outmoded: the teaching methods and strategies that many science teachers employ are largely not grounded in pedagogical research (Banilower, Smith, Weiss, & Pasley, 2006; Weiss, Pasley, Smith, Banilower, & Heck, 2003). The science education reform literature points unequivocally to inquiry-based instructional methods as a key to reform (American Association for the Advancement of Science, 2001; National Research Council, 1996, 2000), with decades of educational and cognitive research identifying inquiry-based instruction as a more effective paradigm (Schroeder et al., 2007; Minner, Levy, & Century, 2010). Second, even if pedagogical methods are sound, science curricula in the US are largely splintered, unfocused, and incoherent when compared to international standards (Schmidt, Wang, & McKnight, 2005).

Inquiry-Oriented Instructional Methods

A different approach contrasts the drill-and-skill, recall-heavy environment of many contemporary high school science courses: inquiry-oriented pedagogy. In *A Framework for K-12 Science Education* (National Research Council, 2012), the NRC identified the need to articulate what exactly is meant by the term "inquiry," as it has been interpreted in many different ways over the years. They stress that in inquiry-based approaches to science teaching, it is expected that "students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves" (National Research Council, 2012, p. 30).

True to its name, inquiry learning places emphasis on scientific inquiry, which can refer to both “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work,” as well as student activities ‘‘in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world’’ (National Research Council, 1996, p. 23). In fact, it has been found that scientists’ own knowledge of scientific concepts, inquiry skills, and scientific tools are inextricably bound together (Edelson, Gordin, & Pea, 1999). With this in mind, the fostering of activities in which students model the behavior of scientists is a hallmark of inquiry-oriented approaches to science teaching.

Inquiry-Based Reform

Calls for reform in science education consistently indicate the importance of learning within the context of authentic investigation (American Association for the Advancement of Science, 2001; European Commission Directorate-General for Research, 2007; National Research Council, 2006). This view of the necessary unification of content and process is echoed by the National Science Education Standards (1996), and their follow-up *Inquiry and the National Science Education Standards* (2000). Educational scholars as far back as Dewey

(1938) and even earlier have recommended pedagogy which situates learning within the context of students' worlds. Yet, until relatively recently, broad evidence indicating its effectiveness in enhancing student learning had been limited. Recent broad meta-analyses (Minner et al., 2010; Schroeder et al., 2007) demonstrate consistent gains in conceptual understanding for inquiry instruction over traditional methods. Furthermore, there is some evidence that inquiry strategies improve achievement on standardized tests (Schneider, Krajcik, Marx, & Soloway, 2002). However, data regarding the practice of inquiry-oriented pedagogy in high school science education indicate low overall prevalence. In an observational study that examined the character and quality of teaching practices of a nationally representative group of public high school science teachers, Banilower et. al. (2006) found that lessons which required student engagement in process of science encompassed just a third of all science lessons. Involvement in the process of science is a hallmark of an inquiry-centered approach, and despite the low prevalence of these activities, it was found that these lessons were the only ones likely to actually have a positive impact on student understanding.

Coherence in Science Programs

The wider issues of misaligned curricula and incoherent programs must also be considered, as they impact the context of instructional methods. Two distinct but related measures of coherence will be discussed: curricular coherence and program coherence. Curricular coherence refers to the content of the curriculum, while program coherence refers to the coordinated activities of a system, such as a district, school, or an academic department in a school. These measures of coherence are distinct but interrelated; it could be expected that the teachers in any given school, for example, are more likely to have a coordinated approach and common operational framework (program coherence) if the school employs a thoughtfully-designed, focused curriculum which progresses logically.

The nature of coherence in high school science is discussed by Rutherford, noting that "Things are coherent if their constituent parts connect to one another logically, … to form a unified whole" (2000, p. 21). Kali defines curricular coherence as "a desired quality of science curriculum materials that involves presenting a complete set of interrelated ideas and making connections among them explicit. Coherent curriculum materials illustrate and model integrated understanding … the desired set of connections among scientific ideas that students need as [students] progress through school" (2008, p. 13). Coherent curricula, Kali additionally notes, make explicit connections between prior knowledge, new ideas, and other related ideas. The NRC's recent publication, *A Framework for K-12 Science Education* (2012), further highlights the importance of connections between ideas and courses, suggesting that science curriculum is best developed as a multi-year sequence that helps students develop increasingly sophisticated ideas.

Coherence in the US

How does the US compare in terms of curricular coherence? The curricula of countries whose students scored highest on TIMMS assessments ("A+" curricula), were shown to have fewer topics and were judged as more demanding than curricula in the US (Schmidt, 1999). More examination of US curricula (which were found to be similar nationwide) showed it to be splintered, lacking focus, rigor, and coherence. Topics linger in the curriculum, such that each grade covers many more topics than typical in high-achieving countries (Schmidt et al., 2005). US curricula often include complex advanced topics before the underlying basics, and emphasize vocabulary and classifications rather than key ideas or concepts (Schmidt et al., 2011). These ideas are consistent with the AAAS's Project 2061 curriculum review, which found that while key ideas are generally present in US curricula, they are typically buried between overly-detailed or even unrelated ideas (Kesidou & Roseman, 2002; Rutherford, 2000). These detailed curricular comparisons, however, extend only to the eighth grade. In the US, science courses are largely organized by scientific discipline starting in the ninth grade, and the science curricula to which individual students are exposed become much more diverse due to graduation requirements and electives at the high school level. NAEP and PISA results tell us about the broad impacts of this high school system. A more detailed analysis of high school course sequencing will be discussed later in the Physics First section.

Program Coherence

If curricular coherence refers to the *what*, program coherence is more related to the *how*: the level of coordination and consistency throughout the program. To investigate program coherence at a single school, a construct called Instructional Program Coherence was developed by Newmann, Smith, Allensworth, and Bryk (2001). Schools that demonstrate high levels of instructional program coherence strive toward a common framework for curriculum, instruction, and assessment – all over a sustained period of time. Teachers have shared expectations for student learning, with specific strategies and materials to guide teaching and assessment. These are coordinated at a given grade level, and they proceed logically from one grade to the next with increasing complexity. The working conditions for teachers support the implementation of the common framework, with curriculum, assessments, and teaching assignments remaining stable enough over time that teachers can become experienced with the framework.

As the authors point out, students learning to read (as an example) are more likely to gain the skills and confidence needed to take on more challenging tasks if they learn in settings where all of their teachers approach reading in a consistent manner. When academic experiences are consistent within and among classes and over time, knowledge and skills are developed more effectively when compared to incoherent programs. Teachers working together on activities that are integrated across classes and disciplines can more effectively pool their knowledge and create more effective instructional plans and assessments.

Schools where curriculum and instruction are highly coordinated can expect enhanced student achievement, as students are more likely to learn when their experiences are connected between grades and between classes (Newmann et al., 2001). This study, conducted between 1994 and 1997 in the Chicago Public School District, used survey data from 222 schools in the district and over 10,000 survey responses from teachers and administrators across two data collections. The researchers also conducted field studies at 11 schools to more extensively develop and validate their model of instructional program coherence and to externally verify survey data.

Science programs which demonstrate high levels of program coherence are coordinated both horizontally - between sections of a given course - and vertically, with curriculum, instructional strategies, assessments, and expectations proceed logically from one science course to the next as students progress through high school. Course sequencing is a fundamental aspect of the coherence of high school science programs in the US, and the history of science course-taking and sequencing is discussed next.

Physics First

A modern trend with old roots, the so-called Physics First paradigm reverses the traditional high school science course sequence with the goal of increasing student achievement in science. Understanding why a re-sequencing would be necessary or beneficial requires an examination of the history of science course-taking patterns, which echoes developments in science itself as well as society in the US over the last one hundred twenty years.

Historical Roots

The order in which physical science courses should be taken has been debated since the late 19th century (Sheppard & Robbins, 2009). The National Education Association's 1892 Committee of Ten (CoT) was tasked with rationalizing high school studies, and made a number of influential recommendations which were eventually implemented as college entrance requirements (DeBoer, 1991). The CoT physical sciences subcommittee (physics, chemistry, and astronomy), ultimately favored a chemistry-physics order, explaining that physics required more mathematical sophistication and maturity, while specifically noting that the logical order (in terms of hierarchy of knowledge) would be reversed (Sheppard & Robbins, 2009).

But the CoT had two other science subcommittees: natural history (botany, zoology, and physiology) and geography (physical geography, geology, and meteorology). These divisions are anachronistic to a modern reader, and this is because science itself has changed significantly since the CoT met in 1892. At this time, the atomic nucleus, for example, had not yet been discovered. With this in mind, it becomes clearer that the connections between the physics and chemistry of 1892 were not as numerous or fundamental as we understand them to be today. In turn, the connections between these analytical, experimental disciplines and the "natural history" of 1892 (botany, zoology, and physiology) were largely absent. The disciplines grouped as natural history and geography were highly descriptive, with little if any math, not analytical like physics and chemistry at the time, or indeed as the life sciences are understood to be today (Glasser, 2012; Sheppard & Robbins, 2002).

Ultimately, the full CoT suggested four different high school course sequences, each of which had students taking a course in physical geography (modern readers would see this as an Earth Science course) during 9th grade, physics in 10th, and chemistry in 11th. In this manner, the full committee's recommendations overruled the sequence argument of the physical sciences subcommittee. Noting that many students at this time left school after 10th grade, the goal of this recommendation was to expose as many students as possible to physics (Sheppard & Robbins, 2009). Indeed, the considerations of the CoT were quite different than what we see in modern, compulsory K-12 education in the US.

The Committee of College Entrance Requirements (CCER), which was formed to implement the CoT recommendations, formally recommended physics for 11th grade and chemistry for 12th, further stipulating that only one science course should be required for graduation; any others would be electives (Sheppard & Robbins, 2009). Another contemporaneous development was the Carnegie Unit, which was developed by the College Board to regulate academic credits. An important effect of this regulation was that science education in the US developed within a fixed one-year, one-credit format, which persists to this day as the single-year survey course (Sheppard & Robbins, 2002).

Modern Course Sequencing in the US

With the CoT recommendations placing a descriptive science (physical geography) in the 9th grade, and the CCER placing physics and chemistry in 11th and 12th grade, early high school science was, in a sense, up for grabs. Social changes in the US near the turn of the 19th century led to significant changes in the demographics of US high schools, with the high school population roughly doubling every decade from 1890 to 1930 (Sheppard & Robbins, 2007). The notion that education should prepare students for their lives and not only for college contrasts with the academy-oriented CoT. Within this context, single-year courses (to meet Carnegie Unit requirements) in "general biology" (a concept never discussed by the CoT) were developed. These courses collapsed the fields of botany, zoology, and physiology, and included the new topics of hygiene, nutrition, and food preparation. Enrollment in these new general biology courses grew quickly, with more students taking general biology than physics and chemistry combined by 1930 (Sheppard & Robbins, 2007).

Physics ultimately became an elective in the US, not taken by most students and only offered late in high school. The sequencing argument advanced by members of the physical science subcommittee of the CoT (that physics requires the highest level of mathematical sophistication and maturity) proved more durable than sequencing arguments based on either hierarchy of knowledge or the desire for as many students to take physics as possible. Thus, the sequence which starts with biology in ninth grade, chemistry in tenth, and physics (if at all) in eleventh or twelfth grade - a sequence unique to the US - is better understood as a historical accident than the result of any design (Sheppard & Robbins, 2002).

Defining Physics First

As science itself has fundamentally changed through the twentieth century, more modern calls for making physics the first course in the high school science sequence offer the most applicable theoretical bases. Some of the "early-modern" advocates appeared in the 1970s (Hamilton, 1970; Palombi, 1971), preceding an influential piece by Nobel Laureate Uri Haber-Schaim in *The Physics Teacher* (1984). This article presented an analysis of popular biology, chemistry, and physics textbooks. In the analysis, Haber-Schaim collected concepts from each text that were "prerequisites," in that the concepts were used but not otherwise explained. The biology texts were shown to be filled with prerequisite concepts from the fields of physics and chemistry such as conservation of energy, half-life, photosynthesis, absorption spectra, chemical bonds and reactions, acids and bases, activation energy, and catalysis. The chemistry texts similarly contained prerequisites from physics such as electromagnetic radiation, electric fields, orbital quantum numbers, electron spin, energy level transitions, radioactivity and nuclear disintegration. As there were no biology or chemistry prerequisites in the physics textbooks, Haber-Schaim argued that physics should be taught first. Scientific understanding has expanded and connected the physical and life sciences in ways the CoT could not have forseen; the increasingly apparent role of physics and chemistry as the context of biology has been identified in the life-sciences reform literature as well (National Research Council, 2003).

Project ARISE

Perhaps the most influential advocate in the Physics First movement is another Nobel Laureate, Leon Lederman. Formulated as broad reform effort called ARISE: American Renaissance in Science Education, Lederman and his colleagues produced a report (Lederman,

1998) and penned an eloquent piece in the journal *Science* (Bardeen & Lederman, 1998). Lederman argued for the creation of a three-year, coherent, integrated science sequence honoring the hierarchical nature of sciences, along with an appropriately coordinated math sequence. This sequence would start in ninth grade, with a course centered on physics concepts, with applications of the algebra learned in eighth grade or concurrently. This was to be an inquiry-based course, focused on the physics of the world surrounding students, and emphasizing the physics topics most relevant to chemistry and biology. Tenth grade science would be focused on chemistry: chemical changes, properties, and the periodic table with emphasis on energy-shells. The biology-heavy eleventh-grade course would approach the diversity of life with students well-grounded in atomic and molecular interactions, understanding, for example, the simple physical and chemical principles that undergird our understanding of DNA. Throughout this sequence, ARISE held that the process of science, epistemology, technology, and real-world interdisciplinary phenomena should be highlighted (Bardeen & Lederman, 1998; Lederman, 1998).

A parallel argument for a re-sequenced, integrated, inquiry-heavy high school science curriculum comes from the Biological Sciences Curriculum Study, who argue for biology as a capstone course built upon physics and chemistry (Bybee et al., 2006). This type of approach, like ARISE, is "integrated" in the sense that each course is thoughtfully connected to other courses and that the science program itself is a coherent unit. This is different than "integrated science" which blurs or ignores disciplinary boundaries. Rutherford (2000) notes that integrated course sequences must be designed thoughtfully to ensure that the coherence implicit in a discipline-based course is not lost: “For coherence to prevail, the physics, chemistry, and biology must be woven into a discernible whole that draws on but transcends the coherence that characterizes the individual disciplines” (Rutherford, 2000, p. 27).

Diversity of Implementation

In the time since the ARISE publications, more and more schools in the US have changed their course sequence such that students take a physics-focused course in the ninth grade: around three percent of public high schools, and eight percent of private high schools in the US as of 2005 (Neuschatz et al., 2008). While ARISE may have been an influencing factor, there is tremendous diversity in the programs offered by these schools which Neuschatz and his colleagues classify as "Physics First," in particular with respect to the integrated nature of such programs as envisioned by Lederman (Neuschatz et al., 2008). Lederman himself, in the years since the original ARISE publications, has felt it necessary to repeat his insistence that the revised sequence be integrated and coherent, and emphasizing inquiry-driven pedagogy, not merely a re-sequencing (Lederman, 2005).

In part to address the diversity in approaches to re-sequencing, the American Association of Physics Teachers produced an informational guide on Physics First (2006), describing it as an organizational alternative to the traditional high school science sequence. This guide highlights the diversity of implementations with its suggestion that schools thinking about switching to a Physics First approach "decide whether to invert and integrate the entire introductory course sequence, require physics for all students, or put physics first and allow students to select their own sequence" (American Association of Physics Teachers, 2006, p. 7). While this is reflective of the diversity of approaches which offer physics in the ninth grade, any system which allows for such a variety of course sequences cannot be realistically expected to be coherent.

Part of the difficulty, then, in discussing the potential effectiveness of the paradigm lies in defining what is or is not a Physics First approach. Project ARISE envisions Physic First as a truly comprehensive reform of the science program in high school, but the evidence suggests that few schools go this far (Neuschatz et al., 2008). For the purposes of this study, a school's science program will be classified as Physics First if a majority of students follow a Physics-Chemistry-Biology (PCB) sequence.

The Impact of Physics First on Pedagogy and Coherence

The research on science education reform, as presented in the previous section of this review, is very clear: inquiry-oriented instructional methods are most effective, as are coherent, aligned science programs. Proponents of Physics First believe that schools implementing the approach should have higher levels of inquiry-oriented teaching and more coherent science programs. While a re-sequencing in isolation may not, in itself, impact instructional models, there is reason to believe Physics may be better suited for the integration of inquiry-oriented pedagogy in the ninth grade than is Biology, as discussed below. Similarly, the revised sequence in itself could have only ancillary impact on the coherence of a science program without thoughtful planning and coordinated activity.

The topics studied in introductory physics may be better suited to student-driven inquiry than the topics in introductory chemistry or biology because the topics in introductory physics are more macroscopic. In order to focus on the process of science in addition to the content, students must engage in experimental design and problem solving. Physics First proponents believe that the topics in introductory physics courses are uniquely suited to these learning modes because of the high level of tangibility and accessibility of simple physics phenomena.

When thoughtfully constructed, a ninth-grade physics course can serve as an introduction not only to physics, but also to the scientific process, scientific problem solving, and scientific modes of analysis and communication (American Association of Physics Teachers, 2006).

As the revised sequence parallels the natural order of increasing complexity in these fields of science, students and teachers can forge stronger and more meaningful curricular and cognitive connections between successive courses. Because the revised course sequence allows teachers to build upon students' prior learning in a manner impossible in a traditional sequence, a greater level of science program connectedness is made possible. The science department at any given school must restructure itself to make the change. This restructuring can serve as a motivating factor to connect and align elements of the science program. For these reasons, it is expected that schools employing Physics First will have more coherent science programs.

Physics First in the United States

The most recent and informative source of data about Physics First in the United States is a report produced by the American Institute of Physics, "Reaching the Critical Mass: The Twenty Year Surge in High School Physics: Findings of the 2005 Nationwide Survey of High School Physics Teachers" (Neuschatz et al., 2008). The study classified any school that offered physics for ninth grade students as Physics First. The report estimates that around three percent of public schools and eight percent of private schools had implemented some form of Physics First in 2005.

The method of implementation varies greatly among these schools offering physics for freshmen, particularly so in public schools. At just over half (55%) of public schools, all ninth grade students took physics. At the remaining schools, not all ninth graders took physics;

schools were evenly spread into three groups: those which offered physics only to less advanced students, those which offered physics only to more advanced students, and those which offered physics to a sub-group of ninth graders from across the ability spectrum. The situation in private schools was more consistent: all freshmen took physics at 78% of schools, while 12% of schools offered physics only to more advanced ninth graders, and the rest were evenly split between offering physics only to less advanced students and offering physics to a sub-group of ninth graders from across the ability spectrum.

Furthermore, schools classified as Physics First offered a variety of course sequences after ninth grade. Again, more variety was found in public schools, with just over a third (37%) offering the PCB sequence extolled by Physics First proponents, half (50%) offering PBC, and 13% offering some other sequence. Over half of private schools offered PCB, with 35% PBC and 8% other sequences. Despite the variations in approach, Physics First has one undeniable result, according to the survey: more students take physics. At public Physics First schools, nearly three-quarters (73%) of students took physics, compared to less than a third (31%) at public schools offering a traditional course sequence. Even within traditional course sequences, over half (57%) of students take physics at private schools, while essentially every student takes physics at those private schools which offer Physics First.

The Effectiveness of Physics First

Broad statements about the effect of Physics First on student achievement have yet to be made; this paucity of research has been noted in the literature (Glasser, 2012; M. O’Brien & Thompson, 2009; Pasero, 2001, 2008). At present, Physics First in any variation may not be widespread enough for large-scale studies to have been completed.

One of the first projects to systematically examine schools implementing Physics First (Pasero, 2001) highlighted teacher's qualitative experiences with switching to the sequence. The experiences of chemistry teachers are particularly relevant, because chemistry is most often the tenth-grade science course in both the traditional and Physics First sequences. They reported appreciating students entering their classes with even rudimentary familiarity with concepts such as light, heat, and electrons. They further noted the benefit of students' knowledge of scientific notation and dimensional analysis, neither of which are typically covered in a ninth-grade biology course. Biology teachers, for their part, reported being able to capitalize on students' chemistry knowledge to tackle modern topics such as molecular biology.

The feasibility of teaching physics in ninth grade was also investigated by a study which looked at 321 students in Maine (M. J. O'Brien & Thompson, 2009). The researchers developed an instrument focused on conceptual mechanics understanding, drawing from three well-established physics assessments. This instrument was given to groups of ninth- and twelfth-grade physics students, once as a pre-test and again as a post-test, after students had covered mechanics. Both groups did only slightly better than random guessing on the pre-test, indicating little familiarity with the subject at the outset. Both ninth-grade and twelfth-grade students experienced similar normalized gains and scores on the post-test, despite the advantage of maturity held by the senior physics students. This is not the first study which shows that young students can effectively learn physics concepts. White (1993), conducted a study in which sixth-graders (11- and 12-year-olds) developed conceptual models effectively embodying Newtonian mechanics.

A recent study examined the standardized math test scores of successive grades of students at a small school in Philadelphia as it transitioned to Physics First (Glasser, 2012).

While still a narrow study, it was found that students in the Physics First sequence performed better on the PSAT math section than did matched peers who completed the traditional sequence. A earlier project examined the science achievement levels of 185 students who self-selected into either a traditional science sequence or a Physics First sequence in an Illinois high school (Pasero, 2008). Inspecting gains in science content scores across subsequent standardized assessments vertically aligned to the ACT test, the data indicated small but statistically significant differences in favor of the Physics First sequence. One final report, about a Physics First program at a high school in New Jersey (Goodman & Etkina, 2008), indicated changes in course-taking habits. This school experienced significant increases in both the rates at which students enrolled in AP Physics and received passing scores on the AP Physics exam subsequent to their implementation of Physics First.

Summary

This review of relevant literature discussed science achievement and science literacy among students in the United States. The twin recommendations from science education reform literature: the emphasis on inquiry-oriented pedagogy and the enhancement of programmatic coherence, were detailed. An overview of the history of science course sequencing in the US was presented. Finally, the history of the Physics First movement was examined, as was the theoretical and research basis of the movement, hinged upon inquiry-oriented pedagogy and program coherence.

Chapter 3 - Research Design

The primary goal of this project was to better understand the impacts of the Physics First model within the context of science education reform. As discussed in the last chapter, two primary recommendations of the science education reform literature are the emphasis of inquiry-oriented pedagogy and the enhancement of program coherence. The mechanisms by which advocates suggest Physics First may address these two recommendations were laid out in the previous chapter; the main idea of this study was to determine if teachers at Physics First schools report characteristics suggested by PF proponents. To investigate, physics and chemistry teachers at schools which have established Physics First programs (defined as five or more years of implementation) were interviewed. The following three questions guided the research:

Research Questions

1) How does Physics First influence how physics and chemistry teachers teach?
2) What aspects of the transition to PF do physics and chemistry teachers find challenging?
3) How do physics and chemistry teachers experience the transition to PF differentially?

Population & Sample

The population in focus was high school science teachers at private schools in the US. This decision was made because Physics First is much more common in private schools, and the approaches more homogenous, than in public schools (Neuschatz et al., 2008). The NCES-produced Digest of Education Statistics (National Center for Education Statistics, US Department of Education, 2010) shows student enrollment in grades 9-12 at non-public schools in the US at around 1.4 million in 2008. With the average teacher to pupil ratio (13.1 to one at these schools), this yields just over 100,000 teachers of grades 9-12 at non-public schools

(National Center for Education Statistics, US Department of Education, 2010). In public schools, around 10% of teachers in grades 9-12 are science teachers (Blank, Langesen, & Petermann, 2007). If this proportion is approximately the same in private schools, there should be around 10,000 science teachers in grades 9-12 at private schools. From another perspective, teachers at public schools (around 3.7 million) make up around 88% of all teachers, while those at non-public schools (around 450,000) encompass the other 12%. With around 125,000 science teachers of grades 9-12 in public schools, it could be expected that there are around 17,000 science teachers in non-public schools. Based on these data, it is expected that the population at focus in this study - science teachers in grades 9-12 at private schools in the US - should number between 10,000 and 17,000. With approximately ten percent of private schools offering Physics First programs, there should be between 1000 and 1,700 teachers in PF programs.

This study received the sponsorship of the National Association of Independent Schools (NAIS), whose membership includes over 1100 schools, enrolling over 550,000 students K-12. Using school contact information provided by NAIS, the researcher contacted teachers and department heads via email, inviting them to participate in this research by conducting a telephone interview. Interviews were scheduled when teachers contacted the researcher.

A sample target of ten schools with established Physics First programs was set. Each of these schools was to have had a Physics First program that had all students go through the Physics-Chemistry-Biology sequence, and the program was to have been in place for five or more years. This "age of program" criterion was chosen to limit the study to schools which had mature implementations of Physics First - those which had completed the transition, overcome many implementation issues, and could comment on that process. Furthermore, the goal was to interview a physics and a chemistry teacher at each school. The experiences of chemistry teachers were sought because whether in a traditional BCP or a Physics First PCB sequence, chemistry teachers typically have sophomore students. Because of this fact, chemistry teachers may be uniquely suited to make direct comparisons of the two approaches.

Procedure

After verbally consenting to be part of the project, each participant responded to an interview protocol (Appendix A). Interviews started with questions which identified each teacher's length of experience, how long their school had employed a Physics First approach, and the nature of their Physics First programs. Next, teachers were asked about their personal transition to a Physics First approach and the impacts the shift had - if any - on their teaching. The remainder of the protocol was designed to elicit responses related to the teacher's use of inquiry-oriented pedagogy, and any possible impact the Physics First approach may have had on it. As shown in the protocol, this placed focus on student-designed investigations, extended projects, and group work.

Data Analysis

Interviews were conducted and recorded, and each was transcribed by the researcher; these transcripts formed the study data. Given the impacts of Physics First suggested by proponents (detailed in Chapter 2), an *a priori* approach was employed in data analysis. Before any coding took place, five codes were developed to clarify what proponents suggest about the outcomes of a switch to Physics First. Using Microsoft Word and Excel, the data were first coded according to the *a priori* themes at the statement-level: transcripts consisted of lists of statements; see Interview Transcripts (Appendix B) for more details. Each statement was tagged with one or more code, and overall frequencies of codes were tabulated for physics and chemistry teachers separately. Next, emergent themes were identified by further analysis of the transcripts. This was accomplished by first marking all respondent statements that were relevant to the research questions or the study more broadly, but which fell outside of the *a priori* codes. The methodology endeavored to categorize each statement; in the process of forming and refining codes, narrow categories were combined when appropriate and codes were eliminated if they appeared only once. When all emergent themes had been identified and their indicators defined, the transcripts were coded for a second time according to these emergent themes. Tables 1-3 below display this list of codes, their definitions, and markers in the data; each is described in detail within the text.

The relationship between codes and Research Questions is of the utmost importance for the analyses in this study. Table 1 presents codes relating to pedagogical techniques, which is the focus of RQ1: How does Physics First influence how physics and chemistry teachers teach? Table 2 provides more details for RQ1, presenting sets of codes which applied specifically to either physics or chemistry teachers, and also helps answer RQ3: How do physics and chemistry teachers experience the transition to PF differentially? The single code relating to challenges to the implementation of PF is presented in Table 3, and is at focus in RQ3: What aspects of the transition to PF do physics and chemistry teachers find challenging?

Table 1

Inquiry and Connected Curriculum: Codes, Definitions, and Markers

Code	Definition	Marker
Assessment of Inquiry*	Determined level of implementation of inquiry	All statements relating to the implementation of inquiry pedagogy were inspected (see below)
No Inquiry	No inquiry-oriented pedagogy reported	Teacher did not report implementation of inquiry
Some Inquiry	Some inquiry-oriented pedagogy reported	Teacher reported any use of inquiry pedagogy
Significant Inquiry	Significant inquiry-oriented pedagogy reported	Teacher reported use of one or more inquiry-oriented activities per semester, or reported such activities, with examples, as foundational to their approach
More Inquiry*	More inquiry than prior teaching in traditional approach	Teacher reported greater implementation of inquiry now than in prior, traditional approach
Philosophy Impacts	Departmental or personal philosophy impacts implementation of inquiry	Teacher reported science department or personal philosophy a factor in their implementation of inquiry, independent of Physics First
Connected Curriculum*	Course connected to concurrent math (all teachers) or previous science course (Chemistry only)	Teacher reports own course and other course are in some way connected via curriculum
Prior Content (Chemistry teachers only)	Course positively impacted by content from ninth-grade physics	Teacher reported positive impact on own course from prior ninth-grade Physics course, but does not indicate any curricular connection
Concurrent Math	Impact on or from concurrent math course	Teacher references an *impact* on or from their students' concurrent math class, but does indicate any curricular connection

* *a priori* code

Table 2

Physics- or Chemistry-Specific: Codes, Definitions, and Markers

Code	Definition	Marker
Physics-Only		
More Conceptual*	Greater focus on concepts in ninth grade course	Teacher reported
Less Math*	Less math in ninth grade course	Teacher reported
More Lab Skills	Greater focus on lab skills in ninth grade course	Teacher reported
Chemistry-Only		
Prior Content	Course positively impacted by content from ninth-grade physics	Teacher reported
Better Math Skills	Students have better math skills with ninth-grade physics	Teacher reported
Better Lab Skills	Students have better lab skills with ninth-grade physics	Teacher reported

* *a priori* code

Table 3

Challenges: Code, Definition, and Marker

Code	Definition	Marker
Teacher Balance	More than normal sections of Physics and less than normal sections of Biology during transition to Physics First	Teacher identified this as challenge to transition

The first code was "Assessment of Inquiry," for which all statements relating to the implementation of inquiry-oriented pedagogy were tagged and scrutinized. The operational definition of inquiry for the purposes of coding was the implementation of student-designed investigations, extended projects, and group work. This definition was inherent to the interview protocol, and, in retrospect, can be seen as painting the picture of inquiry-oriented pedagogy in overly-broad strokes. Furthermore, it is difficult to determine a specific level of implementation of inquiry via self-reported data; this is why a frequency-based distinction was developed.

Statements made by respondents were treated holistically: responses prompted by any question in the interview protocol were treated equally. The coding of these statements related to the implementation of inquiry proved to be challenging, as some interpretation was necessary given the definition of inquiry-oriented pedagogy. As discussed further in Chapter 4, this impacted the certainty of the inquiry classifications assigned to each respondent. The following frequency-oriented scheme was developed: if a teacher did not report the implementation of inquiry-oriented practices, the teacher was classified as "No Inquiry." If a teacher reported any inquiry-oriented activities, the teacher was classified as "Some Inquiry." Teachers who reported the use of such activities once or more per semester were given the code "Significant Inquiry." This frequency-based analysis was bolstered by a more qualitative approach as well. Teachers who reported, citing at least one example, that inquiry-oriented activities were a foundation of their approach were also classified as "Significant Inquiry" even if they did not specifically give other details about frequency. Ultimately, the level of student responsibility for the described practices was at the heart of this analysis. If respondents identified practices which were student-designed and conducted, they were classified as "Significant Inquiry." Conversely, if a teacher indicated mostly teacher-structured activities, they were classified as "No Inquiry" or "Some Inquiry."

The next code, "More Inquiry" was triggered by statements indicating the teacher employed more inquiry-oriented instruction than s/he did in a prior, traditional approach. The code "Connected Curriculum" was employed for statements indicating some curricular connection between their course and either their students' concurrent math class (all teachers) or their students' ninth-grade physics course (applicable to chemistry teachers only).

For physics teachers, the shift from a traditional sequence to a Physics First sequence involves teaching younger and less-mature students, while chemistry teachers typically have tenth-grade students in either sequence. Because of this difference, the final two of the *a priori* codes were specific to physics teachers: approaches that are "More Conceptual" and employ "Less Math" (each triggered by statements indicating such) were expected when shifting from eleventh- or twelfth-grade physics to ninth-grade physics (American Association of Physics Teachers, 2006).

In addition to the previously-described *a priori* codes, Table 1 above lists several additional emergent codes, definitions, and markers in the data related to inquiry. Similarly, Table 2 lists both *a priori* and emergent codes specific to physics or chemistry teachers. Themes that were developed *a priori* are identified with asterisks. Findings are discussed in the next chapter.

Chapter 4 - Findings

This study was focused on three questions: How does Physics First influence how physics and chemistry teachers teach? What aspects of the transition to PF do physics and chemistry teachers find challenging? And finally: How do physics and chemistry teachers experience the transition to PF differentially? The answers to these questions will be discussed in turn, but first we will discuss the sample.

Characteristics of the Data and Sample

Teachers from 11 different independent schools with established Physics First programs were interviewed. Interviews were conducted via telephone, with the recordings captured digitally as uncompressed ".wav" files. The transcription process was conducted as close to immediately after the interview as possible, in most cases the same day, with the aid of the transcription software "Express Scribe" which was used to slow down conversations to capture wording accurately. Interview lengths ranged from a low of 19 minutes to a high of 37 minutes, with an average length of 26 minutes. In two cases, teachers from the same school were interviewed back-to-back in the same telephone call; the resulting files were separated and counted individually for the above analysis.

The interviewees' schools were geographically diverse within the United States. The years of Physics First implementation varied from a low of six years to a high of 22 years, with five schools having twenty or more years of experience with Physics First, and an overall average program age of just over 16 years. See Table 4 below for all data regarding sample schools' experience with Physics First.

Table 4

Schools, Teachers, Experience with Physics First, and Assessment of Inquiry

School	Years of Physics First at School	Physics Teacher	Physics Years Experience (total)	Physics Assessment of Inquiry	Chemistry Teacher	Chemistry Years Experience (total)	Chemistry Assessment of Inquiry
1	20	P1	7	Significant	C1	20	No
2	6	P2	20	Significant	C2	8	No
3	11	P3	29	Some	C3	15	Significant
4	21	P4	35	Significant	C4	8	Some
5	20	P5	25	Significant	C5	15	Significant
6	22	P6	39	Significant	C6	11	Some
7	15	P7	8	Some	C7	5	No
8	13	P8	8	Some	C8	40	Significant
9	10	P9	8	Some	C9	26	Some
10	21	P10	40	Significant			
11	17	P11	35	No			
Avg	16		23			16	

Of the 20 teachers interviewed, 11 were physics teachers, 9 were chemistry teachers. The teachers were assigned identifiers by their subject and school number; at two schools it was only possible to recruit a physics teacher to be part of the study. Table 4 above presents data related to teaching experience; the average experience of the teachers in the sample was 20 years. In all cases, teachers had taught within a traditional sequence previously, at their current school before its transition to Physics First or at another school.

Impact on Inquiry-Oriented Pedagogy

Table 4 above shows the assessment of inquiry for the teachers in the sample. Among all 20 teachers, just one in five reported "No Inquiry," just over a third were classified as implementing "Some Inquiry," and nearly half were classified as implementing "Significant Inquiry." Only three teachers (two physics and one chemistry) reported increased implementation of inquiry in their Physics First approach, and nearly a third of teachers (five physics, one chemistry) discussed the impact of departmental or personal philosophy on their implementation of inquiry, external to Physics First ("Philosophy Impacts").

Inquiry-oriented pedagogy is of primary interest in the first Research Question: How does Physics First influence how physics and chemistry teachers teach? The manner in which each respondent received category designations is described in Chapter 3. Nearly all physics teachers were assessed to implement "Some" or "Significant" inquiry (10 of 11). Of these, six were assessed as implementing "Significant Inquiry," four were assessed as implementing "Some Inquiry." Just one physics teacher did not report the use of inquiry. Chemistry teachers were evenly spread among the three categories, with 3 of 9 assessed to implement "Significant Inquiry," 3 of 9 as implementing "Some Inquiry," and 3 of 9 reporting "No Inquiry." Following, see examples of statements that resulted in each classification.

> Teacher P5 "Significant Inquiry"
>
> In the fall, they do a physics of sports project, they research and do a presentation to their class. Then after studying motion they do mousetrap cars. They do a current event science chat, and a photo contest. Many long-term projects, make a music instrument.

> Teacher C5 "Significant Inquiry"
>
> I've always done a project that lasts a couple of months. One project I've been doing recently, starts with a big list of topics, like fMRI, or local climate change, or they can come up with their own, they research it, write a paper, create a digital product like a screencast or a powerpoint, that's a huge one they like, they find something they're interested in, and this is a group project.
>
> For inquiry, mostly I've done simple things, like you have to figure out percent composition of sugar in bubble gum and water in popcorn, and you have a balance and a microwave, and a bunch of gum and popcorn, and they have to figure out how to do it on their own, and I've done some inquiry labs with density.

Teacher P7 "Some Inquiry"

Two things near the end of the year, we do a video project, where they make a video explaining some aspect of physics, so this can be a combination of live video they shoot of themselves, along with explanations and can include screen-casting and voice-over, they can work alone or with a partner.

Teacher C6 "Some Inquiry"

I feel like we do smaller, more frequent labs. The goal was to spend more time on pre-lab and post-lab discussion, so that they get more out of them. Over the course of the year we build up to more complicated labs, but ideally still with the idea that students understand what they're doing as opposed to just following a series of steps. I've taught that way as well, that works fine too, but I feel like students are more engaged with this approach.

The course if very group-work heavy. Student spend a lot of time either with their lab group, who they do pre-lab, post-lab, and presentation with, they also do a lot of problem solving in that group, and a lot of presenting homework problems and lab results in that group. Very group-work heavy.

We haven't brought in any longer-term projects yet, but it's something we talk about how to fit in, but no.

Teacher C7 "No Inquiry"

My approach to lab work is evolving. I don't do a ton of lab work in the beginning, the first quarter, we do a lot more at the end of the first semester and into the second semester, and I know a lot of people think if you're taking a science you should do experimentation, but I don't know, I was a computationalist for my PhD, so maybe that's why I don't think it's as crucial as some people do, to be physically working with chemicals.

We do a lot of individual and group worksheets and practice sheets and stuff like that, but I don't do any projects, and maybe it's because I'm new and I'm trying to get stuff in, but we don't do any projects.

Teacher P11 "No Inquiry"

Not really any projects that last more than a week. At a boarding school, their time is highly structured. No student-designed experiments. I usually arrange it so that they'll do it the way I want them to.

As discussed in Data Analysis section of Chapter 3, the operational definition of inquiry for the purposes of coding was the implementation of student-designed investigations, extended projects, and group work. The coding of statements related to inquiry proved to be challenging, as some interpretation was necessary given the operationalization of inquiry-oriented pedagogy inherent to the interview protocol. This impacted the certainty of the inquiry classifications assigned to each respondent. The level of student responsibility for the described practices was central to the analysis. If respondents identified practices which were student-designed and conducted, they were classified as "Significant Inquiry." Conversely, if a teacher indicated significantly structured activities, they were classified as "No Inquiry" or "Some Inquiry." For more information on the deeper meaning of these codes, see the Discussion in Chapter 5.

The next theme, "More Inquiry" was more directly related to the *impact* of Physics First on inquiry-oriented pedagogy, as opposed to the previous code, which was only an assessment of the level of implementation of inquiry. Just three of the 20 teachers (two physics, one chemistry) reported more frequent implementation of inquiry in their current Physics First approach than previously in a traditional approach. This code was a part of the *a priori* analysis because it is widely suggested by PF proponents that inquiry can and should be enhanced by a switch to PF, but the data indicate that this was not the case in this sample. Following are two examples:

> Teacher P1: We moved from conceptual enriched with mathematics to a more a project-based, inquiry-based model, where they get the concepts, they have projects that they prepare for, and then they also have some math enrichment as well.
>
> Teacher C3: Link between PF and inquiry: yes, but the reason is that in order to teach physics to 9, you have to reinvent the wheel a bit, it has to be a very hands-on, concrete experience; because that's the type of learner you have in the 9th grade. So, by design, the curriculum pushes you in the direction of being more experience-oriented, more

> open-ended in terms of what you do with the kids, so that leads you to the next level, the kids already have experience with it, they're good at it, so you keep going.

The "Philosophy Impacts" code emerged because 6 of 20 teachers (5 physics and 1 chemistry) reported that their science department philosophy or their personal philosophy was a factor in their own implementation of inquiry-oriented pedagogy, independent of Physics First. Two examples:

> Teacher C8: In all of our courses we try to do a lot of inquiry. Students don't go into the lab knowing the answer to the question - not to say that scientists don't know the answer, but as beginners they don't know the answer, they don't know what to expect, it's not simply confirmation of something they read in the textbook. We do what we call informal lab activities, where we provide a lot of the structure and they are filling in the tables and doing some computations and answering some questions, and then once a quarter, at least once - teachers have students write a formal lab report, where they create much more of the structure themselves, and it's usually a bigger problem.
>
> Teacher P2: Concurrent to the switch over to PF we've also been focusing on trying to create more inquiry activities and following the current research in how kids are learning, so we've certainly changed how we do labs, but a lot of it is driven by those other factors than the fact that they're ninth graders
>
> Teacher P5: Is there a relationship between the implementation of projects and Physics First? I don't know, because it's all tied up with what I think is important to teach, and I guess I became convinced that Physics First is important, and I think project-basis is important.

The reality of the implementation of inquiry as presented in this sample is that it is complex, and dependent upon multiple factors. Nearly all teachers who reported an impact of departmental or personal philosophy on their implementation of inquiry (5 of 6) were rated as "Significant Inquiry." This provides evidence suggesting that inquiry is related to other factors aside from Physics First.

Connected Curriculum

Table 5 below displays code frequencies related to curricular connections. Of the twenty respondents, nearly a third related that their course is connected via curriculum ("Connected Curriculum") to either their students' concurrent math course (all teachers) or to their students' ninth grade physics class (chemistry teachers only). While not indicating actual curricular connections, nearly a third of all teachers (mostly physics) indicated an influence on or from their students' concurrent math class ("Concurrent Math"). For the final code related to connected curriculum, "Prior Content," nearly all chemistry teachers indicated positive benefits to their course from their students' ninth-grade physics class.

Table 5

Connected Curriculum: Frequencies of Codes Across All Teachers

Code	Physics (n=11)	Chemistry (n=9)	All Teachers (n=20)
Connected Curriculum	3	3	6
Prior Content (Chemistry-Only)	N/A	8	N/A
Concurrent Math	5	1	6

Within the code "Connected Curriculum" three teachers (two physics and one chemistry) reported connecting to their students' concurrent math course, and three chemistry teachers reported connecting to their ninth-grade physics class. There was no overlap between these two groups (the one chemistry teacher who reported connecting with concurrent math did not report connecting with previous physics), so a total of 6 out of 20 teachers reported that their course is connected via the curriculum to other courses. Examples of such statements:

> Teacher P7: So I work with the math teacher that teaches most of my students, to the extent we can, we will reference each other's curriculum. We can't re-sequence things, like I do trig before they get it. But having seen it with me makes it easier in their math class, that repetition and relevance - that it's being used not just in the math class. I think it makes it all more relevant and helps them retain it. By the same token I refer to their math class. When I have coordinated, I try to make sure we're using the same vocabulary.
>
> Teacher C1: A chemistry class is filled with physics concepts anyway, but I find myself drawing on what the physics teacher does all day long, I'll introduce a lab and say "remember when you did this with …"

In a related theme, "Prior Content," 8 of 9 chemistry teachers reported that their coverage of chemistry topics had been positively impacted by the shift to Physics First. It is important to draw a distinction - "Prior Content" does not indicate connections between courses, as does "Connected Curriculum." Examples of "Prior Content":

> Teacher C9: I found that there were some topics in chemistry that I always sort of pulled my hair trying to get the kids to understand, not the least of which was that there is energy stored in chemical bonds, and you try to explain gravitational PE, they haven't had that yet, so that didn't make a whole lot of sense to them, but after P9, not only did they understand PE and KE, but they had already seen PE, both gravitational and electric, elastic PE - which is a great analogy for energy stored in chemical bonds - and so, that whole part of chemistry became much easier for us to teach.
>
> Teacher C7: The broad concepts of macro-scale potential and kinetic energy is really something I draw upon in my chemistry class, this idea of KE is energy of motion, it hold true in chemistry, but instead of KE of a macroscopic object, we're taking about the motion of atoms and molecules, and then when we talk about PE and heat, I refer all the time to what they did last year, if in physics you're thinking about a ball rolling down a hill, with PE being the energy of position. And if you think of an electron that's further from the nucleus, just like there's a gravitational force pulling the ball down the hill, we've got the coulomb force on the electron. So that's a huge connection that I make, and it takes a long time, but we continuously come back to it.

Continuing with the idea of relationships between courses, in the next code, "Concurrent Math" 6 teachers, (5 physics and 1 chemistry) referenced an impact on or from their students' concurrent math course. Again, similar to "Prior Content," "Concurrent Math" is not indicative of curricular connections, only that teachers noticed an impact or influence.

> Teacher P4: It's a great time to introduce certain mathematical functions, and kids recognize the value of math. For example graphing - for a lot of kids it's a tedious exercise to keep your math teacher happy, but when you graph motion it actually tells a story and increases the value they see in studying math.
>
> Teacher P7: With [ninth grade physics], I feel like it gives an answer to "why do I have to know this" question about algebra and math. They're using it in the physics class kind of at the same time as they're learning about it in math. They're no wait - they're using it in their physics class right away.

Of the 6 teachers who referenced their students' concurrent math course, just two (one physics and one chemistry) reported that those courses are in some way connected, while 4 (all physics teachers) did not report any curricular connection between their science course and their students' concurrent math course. In summary, the three "Connected Curriculum" codes show that most teachers (14 of 20) see impacts or influences between their science courses and either their students concurrent math or prior Physics courses, but only 6 created curricula or engaged in activities which institutionally established such connections.

Impacts on Physics Teachers

We next focus on themes that were only associated with physics teachers. These themes, presented in Table 6, are all relatively straight-forward and could be expected to be the case in Physics courses designed and conducted for ninth-grade students rather than those in eleventh or twelfth grades.

Table 6

Impacts on Physics Teachers: Frequencies of Codes

Code	Physics Teachers (n=11)
More Conceptual (Phys)	7
Less Math (Phys)	11
Order of Topics (Phys)	5
More Lab Skills (Phys)	4

For the code "More Conceptual," 7 of 11 physics teachers reported more a conceptual approach to ninth grade physics when compared to a traditional sequence. As an example, teacher P4 related:

> I think when I had been teaching [physics in eleventh grade], my immediate approach would have been to start doing FBDs [free body diagrams] and trig, components of forces, and attack it that way, whereas I think [with ninth-grade physics], I would have kids think about: what is a force? Give an example of an object on a table, start to ask questions about what forces might be on it, and that's where they might start thinking about force having direction, then throw some numbers in from there.

Continuing to the next code, "Less Math," all physics teachers (11 of 11) reported implementing less math than in a traditional approach. Teacher P7 said:

> In ninth grade physics, obviously we have to teach a course that is lighter on math than it would be if we were teaching it later. Most of my students are in algebra 1, we split it up based on math ability, but in either case, we do less math.

Two more codes provide details on other changes to ninth-grade physics. The first of these, "Order of Topics" emerged because 5 of 11 physics teachers reported changing the traditional order of topics in physics in some way, either by flipping traditional semester content or incorporating a thematic approach such as "the physics of sports." Teacher P9 said this:

> When you're doing intro physics, all the textbooks start with kinematics, and you're worrying about the distinction between velocity and acceleration - it really blows their minds, and if they're challenged by math that can be a tidal wave of information that bothers them, so we start in the middle of the book, we do sounds, waves, and light in the fall.

For the next code, "More Lab Skills," 3 of 11 physics teachers reported a greater focus on lab skills as compared to a traditional approach. Teacher P2 related:

> We are mindful that this is their first year of science in terms of teaching them lab skills, how to make a graph, what it's for, how to make a data table, this is stuff that they would have known how to do when they arrived in junior physics.

Impacts on Chemistry

Almost every chemistry teacher (8 of 9) described positive effects attendant to their students having a physics course in ninth grade rather than a biology course in ninth grade ("Prior Content"). This code is related to the "Connected Curriculum" theme, and was discussed in that section; "Prior Content" is not, however, indicative of curricular connections. Similar to the last set of codes specific to physics teachers, these next themes, presented in Table 7, are to be expected given the simple differences between students arriving in tenth-grade chemistry from a ninth-grade physics course instead of a ninth-grade biology course. Chemistry, as a highly analytical science, may share more in common with physics than with biology, in terms of analytical math and lab skills.

Table 7

Impacts on Chemistry Teachers: Frequencies of Codes

Code	Chemistry Teachers (n=9)
Prior Content (Chem)	8
Better Math Skills (Chem)	5
Better Lab Skills (Chem)	3

For the code "Better Math Skills," 5 of 9 chemistry teachers reported that students are more comfortable with math when compared to students who took ninth-grade biology. Teacher C2 said this:

> With ninth-grade physics, more experience with scientific notation and other math-oriented science allows the chem teacher to focus more on visualizing more abstract things; they've already found a level of comfort with it from the physics.

On the related theme, "Better Lab Skills," 3 of 9 chemistry teachers reported taking advantage of students' better lab skills in a Physics First approach when compared to students coming from ninth-grade biology. Two examples:

> Teacher C3: The preparation from ninth-grade biology and ninth-grade physics is very different. Kids now, they're very comfortable with numerical data, they are good at graphing, we can launch into gas laws more easily.
>
> Teacher C9: I would say taking physics first prepares them for labs skills, graphing, data analysis. In those areas they have a good skill base.

Challenges

To answer Research Question 2, "What aspects of the transition to PF do physics and chemistry teachers find challenging?" just one code emerged from the data. "Teacher Balance," is related to the several-year transition from a traditional sequence to a Physics First sequence.

The ability to answer RQ2 was inadvertently hampered by the design of the study (as discussed in Chapter 5); this code in particular is related to a discrete obstacle which was overcome rather than a broad or long-term challenge.

Five of 20 teachers (3 physics and 2 chemistry) noted that during the transition to PF, there will be several years with a smaller than normal demand for biology teachers and a larger than normal demand for physics teachers. Teacher P11 said the following:

> What happens is that during the transition years, the students who took bio as freshmen are ready to take physics when they're older, meanwhile the next freshmen are taking physics and there's a great need for physics teachers and a smaller need for biology teachers.

Physics v. Chemistry

The final research question, "How do physics and chemistry teachers experience the transition to PF differentially?" is hinged upon analyses embedded in Research Questions 1 and 2. Examining the codes assigned to each respondent in the "Assessment of Inquiry," category, there were no significant differences between the physics and chemistry teachers in the sample. Nearly all physics teachers were assessed to implement "Some" or "Significant" inquiry (10 of 11). Of these, 6 of 11 were assessed as implementing "Significant Inquiry," while 4 of 11 were assessed as implementing "Some Inquiry." Just one physics teacher did not report the use of inquiry. Among chemistry teachers, two thirds (6 of 9) were assessed to implement "Some" or "Significant" inquiry, but were evenly spread among the three categories, with 3 of 9 were assessed to implement "Significant Inquiry," 3 of 9 as implementing "Some Inquiry," and 3 of 9 reporting "No Inquiry." A slightly higher proportion of physics teachers were assessed at

"Significant" inquiry, but it is difficult to give much credence to this, given the small size of the sample and smaller number of chemistry teachers than physics teachers in the sample.

For the theme "Concurrent Math," 5 of 11 physics teachers referenced the impact on or from their students' concurrent math course, while only 1 of 9 chemistry teachers did this. Additionally, one group of themes, "Prior Content," "Better Math Skills," and "Better Lab Skills," were only associated with chemistry teachers, because they are related to connections to ninth-grade physics, the previous year's science course. Similarly, a group of themes "More Conceptual," "Order of Topics," "More Lab Skills," and "Less Math," were only associated with physics teachers, because they relate to changes enacted to teach a traditionally junior-year course for ninth-grade students.

Summary

The codes which applied to each Research Question were discussed in turn. To answer the first Research Question, "How does Physics First influence how physics and chemistry teachers teach?" the transcript data were analyzed looking for statements relating to inquiry and curricular connections. The next question, "What aspects of the transition to PF do physics and chemistry teachers find challenging?" was discussed with just one emergent theme. Finally, Research Question 3, "How do physics and chemistry teachers experience the transition to PF differentially?" was tackled by analyzing differential theme frequencies between physics and chemistry teachers within the analyses of previous two Research Questions. This concludes the findings section. We turn next to a discussion of these findings.

Chapter 5 - Discussion of Findings

The analyses of individual themes were presented in the previous chapter, and now we move on to a higher-level analysis of the data. We turn first to the primary relationship of interest in this study, that between Physics First and inquiry-oriented pedagogy.

The Impact of Physics First on Inquiry

Gauging the impact of Physics First on inquiry-oriented pedagogy was a central goal of this project. First, it is important to recognize that the assessment of inquiry for the purposes of this study was somewhat blunt, with just three levels: "No Inquiry," "Some Inquiry," and "Significant Inquiry." This classification scheme certainly does not completely capture the wide range of teaching practices in which teachers in the study must engage. This was, however, determined to be the most justifiable classification scheme, given the unreliability inherent to self-reported data and the emergent themes which influenced the findings related to the implementation of inquiry (in particular the effect of personal or departmental philosophy). Physics and chemistry teachers did not significantly diverge in their assessed levels of inquiry.

There did not appear to be significant school-level matching of inquiry; just one pair of teachers who worked at the same school were both assessed at "Significant Inquiry" (P5 and C5). There were two dichotomous pairs, in which one teacher rated at "Significant" while the other did not report the use of inquiry. In both cases, the physics teacher reported the implementation of significant inquiry. The different experiences of physics and chemistry teachers are further discussed in the Physics v Chemistry section below.

The data indicated a relatively high level of inquiry-oriented pedagogy across the sample when compared to broad studies, which typically indicate a very low level of implementation of inquiry-oriented pedagogy in most high school science courses (Banilower et al., 2006). Most teachers (16 of 20) described the implementation of inquiry in their courses. Of those 16 teachers, 9 were assessed to implement "Significant Inquiry." It is important to understand that the Physics First approach on its own cannot possibly account for these relatively high levels of inquiry reported by the respondents. In fact, only 3 of the 20 teachers interviewed specifically related that the shift to PF itself resulted in greater implementation of inquiry; all three of these teachers were assessed as implementing "Significant Inquiry."

At the outset of this study, a major goal was to investigate the impact of the PF approach on inquiry-oriented pedagogy by having teachers contrast their teaching within PF to their teaching previously. This turned out to be very difficult, because most respondents switched to PF so long ago that it was impossible to get a clear sense of their teaching practices before PF. When respondents compared their implementation of inquiry under a Physics First approach to their implementation under a traditional approach, they were implicitly comparing their current teaching (in a Physics First approach by their inclusion in the sample) to their past teaching, in many cases a significant number of years in the past, given the maturity of their Physics First programs and the amount of teaching experience among the sample.

It is important to understand that teachers grow and learn over time, and their philosophies and pedagogical practices shift. Take for example a physics teacher who cites employing more inquiry currently within a Physics First program than she did when teaching in a traditional sequence 15 years ago. We have no idea how much of the pedagogical shift can be attributed to Physics First. Thus, the question of the impact of PF on inquiry was significantly scaled back to a question of the current level of implementation of inquiry, as reported by the teachers. As discussed next, there are also other important factors that influence the implementation of inquiry-oriented pedagogy.

Other Impacts on Inquiry

No teachers specifically cited increasing inquiry as a reason for shifting to PF, but nearly a third of respondents (6 of 20) described influences on inquiry oriented pedagogy stemming from departmental approach or personal philosophy. This is reasonable to expect: if a science department (or school) commits to the implementation of inquiry-oriented pedagogy, it stands to reason that they can expect high levels of inquiry, whether they use a Physics First approach or not. Similarly, if a teacher has a personal philosophy (perhaps influenced by professional development) that is supportive of inquiry, it stands to reason that high levels of inquiry could be expected in that teacher's classes, again whether his or her school uses a Physics First approach or not. This is borne out in the data: of the 6 teachers who described the influence of department or school philosophy on their implementation of inquiry, 5 were rated as "Significant Inquiry," and the sixth as "Some Inquiry." The implementation of inquiry-oriented pedagogy depends on many factors and could not be expected to miraculously increase when the sequence of high school science courses is inverted.

Connected Curriculum

Proponents of Physics First suggest that within the approach, successive science courses should be integrated into a three-year sequence, and this should be connected to students' concurrent math courses. There were two ways in which teachers could indicate that their course was connected to other courses, and they differed depending on the teacher type. The link between math and the physical sciences is well-understood, and indeed nearly a third of teachers referenced an impact on or from their students' concurrent math course.

Yet, of those 6 teachers only 2 (one physics and one chemistry teacher) reported actual connections between concurrent science and math courses. Chemistry teachers in the sample clearly indicated a preference for their students to have a physics class rather than a biology class in ninth grade, with nearly all taking advantage of ninth-grade physics content, a majority reporting their students arrive with better math skills, and some reporting that their students arrive with better laboratory skills. Yet only a third of chemistry teachers reported actual connections between their chemistry course and their students' previous physics course. It seems as though teachers adjust to the new sequence, but do not necessarily leverage advantages from it.

Thus, while Physics First proponents suggest a three-year program integrating science and math, this is not evident in reality as presented in this sample. Teachers definitely recognized impacts on and from other science and math courses, but for the most part did not report that their classes were connected by curriculum to those other science or math classes. As an example, many chemistry teachers cited impacts from their students' prior physics class, but they mostly did not report modifying their chemistry curriculum to connect to their students' experiences in that physics class. Similarly, physics teachers recognized the impact on and from their students' math class, but only one reported actually coordinating with the math department.

Switching to PF does not appear to lead, on its own, to any dramatic changes in program coherence - beyond those that derive from the change in sequence itself. Chemistry teachers simply become able to take advantage of physics content (and report some other positive impacts from ninth-grade physics). There was no relationship found between those teachers who reported a connected curriculum and their assessed implementation of inquiry; those six teachers were spread among the three inquiry classifications.

Impacts on Physics Courses

Physics First proponents argue a physics course for ninth-grade students should be more conceptual and employ less math, and this was clearly borne out in the data. All physics teachers reported using less math, and a majority reported a more conceptual approach. So it would seem that a change to a Physics First approach is very likely to impact the curriculum and teaching approach of a school's physics courses.

Nearly half of physics teachers reported some change in the order of topics traditional to introductory physics, while some physics teachers reported a greater emphasis on lab skills with physics shifted to be first in the high school science sequence. These are both changes which are could be consistent with inquiry-oriented pedagogy, but not necessarily.

Challenges to the Implementation of Physics First

One relevant code relating to challenges to the implementation of Physics First emerged from the data, but the scope of findings related to implementation challenges is limited. This code is related to the balance of teachers during the first years of implementation of Physics First. If a school employs a traditional BCP sequence, and switches to Physics First starting with Year 1, the previous year's chemistry students will still need to take physics as juniors, but the rising freshmen will also be taking physics, and little or no biology will be offered in Year 1. Year 2 will be the same as Year 1, while the final group of students who took biology in ninth grade take physics in eleventh grade. Finally, in Year 4, the transition will be complete, and the number of physics and biology courses will return to normal. The intervening years must be handled somehow, either by biology teachers teaching out of subject area, via new hiring, or timing the transition to coincide with a biology teacher's retirement. None of these are ideal, and keeping all current teachers fully employed during and after the transition is a prerequisite for many schools.

Findings in this study related to challenges encountered in the implementation of Physics First must be limited in scope. Most teachers in the sample did not specifically mention a challenge in the transition to Physics First. There are several reasons this could be the case. First, it could be that the interview protocol employed did not elicit valuable responses related to challenges. Second, while all of the teachers in the sample taught previously in a traditional sequence, not all teachers were at their current school when it made the transition, so not all teachers encountered a departmental shift they could reference (though all could discuss their own personal transition). Second, and perhaps most importantly, with an average Physics First program age of 16 years (including five schools with over twenty years' experience), the transitions at most schools happened long ago, often with different faculty. Furthermore, this long average program history makes it more likely that these programs are successful - certainly some schools that tried but did not make smooth transitions to Physics First chose to return to a traditional sequence and could not have been part of this sample. The issues that came up as challenges may best be interpreted as adjustments, which were all overcome such that the schools in the study went on to become well-established Physics First schools.

Physics v. Chemistry

Physics teachers and physics courses seemed to be more impacted by the shift to Physics First than chemistry teachers and chemistry courses. This could be partly expected because the actual transition to Physics First is of greater magnitude for physics teachers than for chemistry teachers. Physics teachers transition to students of a different age and typically make changes to the traditional format and content of the course (discussed previously). Chemistry teachers, on the other hand, can experience the transition more passively, and may not need to make changes to their own course.

There was very little consistency in code frequency between physics and chemistry teachers at the same school. Physics teachers could be counted on to discuss things in a manner similar to other physics teachers, and the same held true for chemistry teachers. This again points to the differences in transition experiences for physics and chemistry teachers.

The physics and chemistry teachers in this sample were assessed as implementing similar levels of inquiry. The average years of teaching experience in the sample was slightly higher among physics teachers (20 years) than among chemistry teachers (16 years). All teachers who were assessed as implementing significant inquiry had 15 or more years of experience, with an average of 26 years of teaching. On the other side, however, there were no clear experience patterns in those teachers who did not report the implementation of inquiry. The sample size was unfortunately not large enough to further investigate the relationship between teaching experience and the implementation of inquiry.

Summary of Findings

Does Physics First lead to increased implementation of inquiry? Not according to this study. There were relatively high levels of inquiry reported, but nothing indicated that this was caused by the Physics First approach. Does Physics First lead to greater coherence in science programs? Again, not according to this study. At best, teachers recognize impacts on and from prior and concurrent science and math courses, but do not take advantage of them in the manner suggested by Physics First proponents.

Recommendations & Limitations

This was a small study with only 20 respondents from 11 schools. While the sample was geographically diverse within the United States, the sample could not be seen as representative of high school science teachers in general. Given the diversity of forms of Physics First within the United States, especially in public schools, this sample may not be representative of Physics First schools (depending on the definition one employs). However, this sample may be representative of independent schools in the United State with established Physics First program, but with an average length of PF implementation of over 15 years, the schools in this study may more accurately represent exemplary (or extraordinary) Physics First programs. Furthermore, as discussed earlier, this study did not collect a great deal of data about challenges inherent in the transition to Physics First.

Recommendations for Further Research

This study suggests that Physics First may be related to inquiry-oriented pedagogy, but it is important to recognize that other factors significantly influence the implementation of inquiry. To better understand the transition to Physics First - both in terms of challenges and impacts on pedagogy - it would be illuminating to track a science department from its first conversations about Physics First through to a mature implementation of the approach. Only by gaining detailed knowledge about each member in a given department over the entire process of the transition could the impact of Physics First on pedagogy be fully understood, and even in such a case the insight gained would in many ways still be specific to the teachers and school in focus.

Yet, given the findings presented above, perhaps a more fruitful approach would be to thoroughly investigate a small sample of schools which demonstrate high levels of inquiry-oriented pedagogy across all science classes, regardless of their course sequencing scheme. A study of this sort could lead to better understanding of the various factors which support and result in the implementation of inquiry-oriented pedagogy.

Another possible direction for future research is a more detailed investigation of the impact of Physics First on program coherence. This study just scratched the surface of this relationship. Respondents in this study recognized impacts on and from other science and math courses, but largely did not indicate leveraging these impacts by forging curricular connections between physics and subsequent chemistry courses, or between physics or chemistry and students' concurrent math courses. Clarifying the extent to which this is the case more broadly - that the connections are recognized but not leveraged - would be helpful both for understanding the impacts of Physics First and for improving its implementation. To truly understand the impact of a department-wide change like a shift to Physics First, the experiences of all science teachers must be sought; the experiences of biology teachers (especially with respect to inquiry) would be particularly informative.

Recommendations for Independent Schools

This study examined independent school science teachers, because Physics First in its most consistent form is far more common in these schools than in the public sector. Perhaps a transition to Physics First is best undertaken as a call-to-arms for the teachers in a single science department. If a science department is interested in and capable of significant curricular innovation and revision, the transition to Physics First may serve as a lens for focusing curriculum and pedagogy. But this can only occur if a science department explicitly incorporates inquiry-oriented pedagogy and explicitly connects its science (and math) courses. Science department philosophy and teacher philosophy both influence the implementation of inquiry, so these are important considerations as well.

Conclusion

Science education in the United States needs help. Reformers recommend enhancing inquiry-oriented pedagogy and program coherence. Some schools have switched to Physics First, which inverts the traditional high school science sequence. The teachers sampled in this study reported relatively high levels of inquiry-oriented pedagogy, but the situation was shown to be complex, because other factors influence inquiry-oriented pedagogy in addition to or aside from Physics First. Teachers adjusted to the revised course sequence, and noted advantages to the approach, but largely did not leverage these advantages to create more coherent curricula.

References

American Association for the Advancement of Science. (1998). *Blueprints for Reform*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (2001). *Designs for Science Literacy*. New York, NY: Oxford University Press.

American Association for the Advancement of Science, F. (1990). *Science for all Americans*. New York, NY: Oxford University Press.

American Association of Physics Teachers. (2006). *Physics First: An Informational Guide for Teachers, School Administrators, Parents, Scientists, and the Public*. College Park, MD: American Association of Physics Teachers.

Banilower, E. R., Smith, P. S., Weiss, & Pasley. (2006). The status of K-12 science teaching in the United States: Results from a national observation survey. *The impact of state and national standards on K-12 science teaching* (pp. 83–122). Greenwich, CT: Information Age Publishing.

Bardeen, M. G., & Lederman, L. M. (1998). Coherence in Science Education. *Science, 281*, 178–179.

Blank, R., Langesen, D., & Petermann, A. (2007). *State Indicators of Science and Mathematics Education 2007*. Washington, D.C.: Council of Chief State School Officers.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. Colorado Springs, CO: BSCS.

Committee on Science & Engineering, National Academy of Sciences. (2007). *Rising Above the Gathering Storm*. Washington, D.C.: National Academies Press.

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

Dewey, J. (1938). *Experience and Education*. New York, NY: Kappa Delta Pi.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design. *Journal of the Learning Sciences*, *8*, 391–450.

European Commission Directorate-General for Research. (2007). *Science Education Now: A Renewed Pedagogy for the Future of Europe*. Luxembourg: Office for Official Publications of the European Communities.

Glasser, H. M. (2012). The Numbers Speak: Physics First Supports Math Performance. *The Physics Teacher*, *50*, 53–55.

Goodman, R., & Etkina, E. (2008). Squaring the Circle: A Mathematically Rigorous Physics First. *The Physics Teacher*, *46*, 222–227.

Haber-Schaim, U. (1984). In My Opinion...High School Physics Should be Taught Before Chemistry and Biology. *Physics Teacher*, *22*, 330–32.

Hamilton, D. K. (1970). Physics and the High School Sophomore. *The Physics Teacher*, *46*, 222–227.

Kali, Y. (2008). *Designing Coherent Science Education: Implications for Curriculum, Instruction, and Policy*. (Y. Kali, M. C. Linn, & J. E. Roseman, Eds.). New York, NY: Teachers College Press.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching, 39*, 522–549.

Lederman, L. (1998). *ARISE: American Renaissance in Science Education*. Batavia, IL: Fermi National Accelerator Laboratory.

Lederman, L. (2005). Physics First? *The Physics Teacher, 43*, 6–7.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*, 474–496.

National Center for Education Statistics, US Department of Education. (2007a). *Highlights from PISA 2006: Performance of U.S. 15-Year-Old Students in Science and Mathematics Literacy in an International Context*. Washington, D.C.: US Department of Education.

National Center for Education Statistics, US Department of Education. (2007b). *Advanced Mathematics and Science Coursetaking in the Spring High School Senior Classes of 1982, 1992, and 2004*. Washington, D.C.: US Department of Education.

National Center for Education Statistics, US Department of Education. (2008). *Highlights From TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context*. Washington, D.C.: National Center for Education Statistics.

National Center for Education Statistics, US Department of Education. (2010). *Digest of Education Statistics, 2010*. Washington, D.C.: National Center for Education Statistics.

National Center on Education and the Economy, US Department of Education. (2006a). *Tough Choices or Tough Times: The Report of the New Commission on the Skills of the American Workforce*. Hoboken, NJ: Jossey-Bass.

National Center on Education and the Economy, US Department of Education. (2006b). *The Nation's Report Card: Science 2005*. Hoboken, NJ: Jossey-Bass.

National Center on Education and the Economy, US Department of Education. (2011). *The Nation's Report Card: Science 2009*. Hoboken, NJ: Jossey-Bass.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: The National Academies Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, D.C.: National Academies Press.

National Research Council. (2003). *Bio 2010: transforming undergraduate education for future research biologists*. Washington, D.C.: National Academies Press.

National Research Council. (2006). *America's Lab Report*. Washington, D.C.: National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

National Science Board. (2007). *National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Engineering, and Mathematics Education System.* Washington, D.C.: National Science Foundation.

Neuschatz, M., McFarling, M., & White, S. (2008). *Reaching the Critical Mass: The Twenty Year Surge in High School Physics: Findings of the 2005 Nationwide Survey of High School Physics Teachers.* Melville, NY: American Institute of Physics.

Newmann, F. M., Smith, B., Allensworth, E., & Bryk, A. S. (2001). Instructional Program Coherence: What It Is and Why It Should Guide School Improvement Policy. *Educational Evaluation and Policy Analysis, 23*, 297–321.

O'Brien, M. J., & Thompson, J. R. (2009). Effectiveness of Ninth-Grade Physics in Maine: Conceptual Understanding. *The Physics Teacher*, *47*, 234–239.

O'Brien, M., & Thompson, J. (2009). Effectiveness of Ninth-Grade Physics in Maine: Conceptual Understanding. *The Physics Teacher*, *47*, 234–239.

Palombi, J. (1971). The Illogic of Teaching Bio Before Chem and Physics. *The Physics Teacher*, *9*, 39–40.

Pasero, S. (2001). *The State of Physics First Programs*. Batavia, IL: Fermilab Education Office.

Pasero, S. (2008). *A quantitative study of a physics-first pilot program*. Batavia, IL: Fermilab.

Rutherford, F. J. (2000). Coherence in High School Science. *Making Sense of Integrated Science*. Arlington, VA: National Science Teachers Association.

Schmidt, W. (1999). *Facing the consequences: using TIMSS for a closer look at U.S. mathematics and science education*. New York, NY: Springer.

Schmidt, W., Leroi, G., Billinge, S., Lederman, L., Champagne, A., Hake, R., Heron, P., et al. (2011). *Towards Coherence in Science Instruction: A Framework for Science Literacy*. East Lansing, MI: Michigan State University.

Schmidt, W., Wang, H. C., & McKnight, C. C. (2005). Curriculum coherence: an examination of US mathematics and science content standards from an international perspective. *Journal of Curriculum Studies*, *37*, 525–559.

Schneider, R. M., Krajcik, J., Marx, R. W., & Soloway, E. (2002). Performance of Students in Project-Based Science Classrooms on a National Measure of Science Achievement. *Journal of Research in Science Teaching*, *39*, 410–422.

Schroeder, C. M., Scott, T. P., Tolson, H., Huang, T., & Lee, Y. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching*, *44*, 1436–1460.

Sheppard, K., & Robbins, D. M. (2002). Lessons from the Committee of Ten. *The Physics Teacher*, *40*, 426–431.

Sheppard, K., & Robbins, D. M. (2007). High School Biology Today: What the Committee of Ten Actually Said. *CBE - Life Sciences Education*, *6*, 198–202.

Sheppard, K., & Robbins, D. M. (2009). The ``First Physics First'' Movement, 1880--1920. *The Physics Teacher*, *47*, 46–50.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). Looking inside the classroom. *Chapel Hill, NC: Horizon Research Inc*.

White, B. Y. (1993). ThinkerTools: Causal Models, Conceptual Change, and Science Education. *Cognition and Instruction*, *10*, 1–100.

Appendix A: Interview Protocol

Consent Script: Thank you for taking the time to talk with me today. My name is Mechum Purnell. I'm a doctoral candidate in the Educational Leadership Program at UCLA, and I'm conducting a study under the supervision of Prof. William Sandoval in UCLA's department of Education. I'm interested in understanding the experience of teachers at independent schools with the transition to Physics First. My goal is that this understanding can help other schools and teachers decide whether or not Physics First might be right for them, and how they might move in that direction if they chose. The study poses no physical or psychological risks, and your responses will be completely anonymous. Your participation in the study is completely voluntary, and you can withdraw from participation at any time. I would just like to ask you some questions about your experiences with Physics First at your school, and the whole conversation should take about 30 minutes. I am going to record our conversation so that I get an accurate record of your thoughts. I'm talking with several teachers at different schools, and my aim is to see what is common about teachers' experiences with Physics First, and what might vary across schools or teachers. Do you have any questions?
[answer their questions]

OK, now I have to ask you officially, do you consent to participate in this study?

[IF NO] "OK. Thank you very much for your time. Good bye."

[IF YES] "Great. Thank you. Let's get started. I'm going to start recording our conversation now. Remember, you can stop at any time for any reason. Ready?"

1. How long have you been teaching at [your school]?
2. Can you tell me about the Physics First (PF) program at your school, and your involvement with it? (Verify years the school has done PF and years teacher has taught in PF. Also verify the form of the program.)
3. Were you teaching at this school when the switch to PF was made?

   a. [YES] Tell me about the transition. What was it like for you?

   b. [NO]. Did you come from a school that was already doing PF, or was PF new to you when you got to this school?

   i. [NEW] What was the move to PF like for you when you got to this school?

   ii. [NOT NEW] Were you part of a switch to PF at your previous school? If so, what was that like for you?
4. Let's think about a big topic in (physics/chemistry) like (forces and motion/reactions). How do you go about trying to teach (forces and motion/reactions)?

   Follow-up probes (depending on answer) to clarify or extend: Extended projects? (describe) / Group work? (describe) Do students design their own experiments or do you provide procedures? (describe)
5. Think back to how you taught (forces and motion/reactions) before you changed to PF. How was your teaching of (forces and motion/reactions) different?

Clarifying / Extending Questions (not needed if already answered)

6. How has PF changed how you teach (physics/chemistry)?

7. How have your assumptions about what students know at the start of the year changed since moving to PF?

8. Has your approach to experiments and projects changed since you started teaching in PF? (describe)

9. How often do students in your course do experiments or investigations they've designed themselves? [get their answer] Can you tell me about an example they've done this year?

10. How often do students in your course do extended projects of more than a week? [get answer]. Can you tell me about an example they've done this year?

OK. Well, that's all the questions I have for you. Thank you very much. Do you have any questions for me?

[answer them]

Thanks again! Goodbye.

Appendix B: Interview Transcripts

P1: I came in using Hewitt, important to connect with concepts then math

Dichotomy of 9th: very wide math ability (math: alg 1 to h alg 2 = very wide math ability)

We moved from conceptual enriched with mathematics to a more a project-based, inquiry-based model, where they get the concepts, they have projects that they prepare for, and then they also have some math enrichment as well. That has worked pretty well with the different [math] abilities and it gives them a different way to attack physics knowledge; talk about the physics of driving, the physics of sports, electric circuits and wiring in homes.

Active Physics: first project: do a presentation about safe driving to a panel, includes poster or power point, a written report. Another project: physics of sports: choose a sport, make a newscast-style presentation of the physics of the sport. Another project, wire a home for a family of 4 with energy and power limits; discuss necessary appliances, wire, etc.

Own study of Physics was traditional in HS then at college level; when started the job, wasn’t convinced about PF. Needed to let go of the math, because you know in a junior or senior level class the math is central, and math ability is central, and depends on equations and rules like that, so really bringing it down a notch and really sharing with students the conceptual basis, and honing in their observational skills, prompting them to learn the skills they need to do labs, so that became my focus, but it took some time to embrace that.

PF allows for a direct use of concurrent math (graphs, proportionality, in addition to mechanics-related math)

Some students are ready for a full-blown math-heavy physics; will offer an honors level in the future to better prepare for IB physics;

C1: Origin: wanted to revamp curr, decided PF better for cognitive dev, led to better understanding in Bio (P-C-good background in phys sciences).

The challenge in transition from junior or senior chemistry to sophomore chemistry: Finding a textbook appropriate for the level, once good textbook, really no problem.

Soph: "for the bulk of chemistry they were absolutely fine, but for some of the more advanced topics were not ready for developmentally," so delete some of the more advanced chemistry in the end; dichotomy of 10th grade: some are still developmentally freshmen while some are already in junior year; half ready for advanced, half not, so split into regular and honors chem; directly related to mathematical ability; reinforcement v enrichment.

students in PF have a skill set that's really well developed by the time they reach my class, so they understand immediately when I start talking about energy: potential, kinetic; this background of how the physical world operates;

when I introduce concepts like the law of conservation of mass or matter, they already know about the law of conservation of energy, so it gives them experience to draw from, that I can use as a building block or stepping stone.

A chemistry class is filled with physics concepts anyway, but I find myself drawing on what the physics teacher does all day long, I'll introduce a lab and say "remember when you did this with"; they've got more of a background when they get to me, so I don't have to do as much instructive teaching.

And since the 9th grade physics class is all project-based lab-based, they've got well-developed lab skills; they can handle equipment and set up the probeware.

Do far more lab work than in traditional, I always tended toward lab-based chem, but we're generally doing labs or other hands-on 2 of 4 days each week, always something physical they're doing to help bring the concepts alive, and give them the base to move on when you start talking about chemistry that underlies biological systems.

Outcome of PF: every graduate has 4 years of a science, every kid has PCB+, positive impact on subsequent STEM enrollment

For IB you have to write an extended essay which includes research project; will need to do more projects in later years so will be adding more of that

P2: Used to have a unique process-centric 9th grade science course, but due to pressures from parents and college transcripts, had to move that course out, so looked at how to incorporate general lab skills in the ninth grade course that was more traditional and physics lends itself to that the best of the 3 central sciences.

Also looked at Bio and thought it would be great to have chem and phys before bio (and I had taught at a PF school before)

Also wanted all students to take physics, increased from 65% to almost all

Implemented change over 4-year period. Started with highest-math, figured if they couldn't do it, it was a bad idea. But they did great, outperformed Juniors. So then we brought in the entire 9th grade.

We began by offering a class that was connected to their math class. Tried to coordinate to push H kids and support alg 1 kids.

Have since moved away from this, and will have all students in once course. Alg 1 kids had problems larger than math, and keeping them together wasn't best from them.

I pushed the department in the direction, but Bio teachers redesigned and implemented 11th bio, chem teachers looked at chem, introduced chemcomm (theme-based conceptual chem), physics teachers modified and continue to modify the physics curriculum.

Mostly a question of assumptions, we're not really teaching at that different a level, we took out some of the trig and some of the more complicated quadratic equations, but we don't assume that students are comfortable with their algebra, we make a point of guiding them through it over the course of the year

We are mindful that this is their first year of science in terms of teaching them lab skills, how to make a graph, what it's for, how to make a data table, this is stuff that they would have known how to do when they arrived in Junior physics

We've always as a department really focused on the concepts of physics over the equations of physics, so that was not a big change that we had to make

By the end of the year, the students have done what most people would think of as a junior physics class

We have to pay more attention with lab work: more careful with directions;

Concurrent to the switch over to PF we've also been focusing on trying to create more inquiry activities and following the current research in how kids are learning, so we've certainly changed how we do labs, but a lot of it is driven by those other factors than the fact that they're ninth graders

Description of inquiry activities: we'll introduce a topic, give a lot of information, here are some materials:

Ex: first three days of static electricity are experiments with almost no discussion of electricity or charge, hoping that they can discover some of the concepts, then we cycle back around and put the content in place. We may start a unit that way half the time, then we'll also incorporate some of the more standard lab-activities.

Project Ex: research project on seismic waves, related what they learned about waves and create a presentation of any type: board game, movies, paper, poster.

Inquiry is more important for the 9th graders. They're not necessarily going to be good learners in a "traditional" lecture-style environment; that's not what they experienced in middle school, they have trouble sitting still. While I actually do think that any physics course should be inquiry-based, I think it's more important for ninth-graders.

C2: Data on impact of PF: midterm chem grades are better for PF than in trad.

Reasons: more comfortable with math in science b/c they were forced to do that and made transition to abstract thinking in P9

P9 = more experience with scientific notation and other math-oriented science allows chem teacher to focus more on visualizing more abstract things; they've already found a level of comfort with it from the physics.

Chem courses: not really project-based or integrating open-ended investigations

2 levels of chem: one traditional, lots of content, math-heavy. Other chemistry in community, taught in context, very different, very lab-based and hands-on. Theme-based.

Totally changed biology

Our sticking point has been that this new track may make it more difficult for them to take all three AP science classes we offer, and it's been tough getting our academic deans on board with our 11th grade students possibly doubling up in science, so they could accommodate that AP desire.

It's a matter of the political atmosphere, and trying to move other people into thinking about science in a different way, coupled with simply doing this change, as I mentioned, is like performing surgery on a living patient, when you shift senior physics down to the freshmen year, biology ends up getting caught, I've been trying to puzzle this out, we wind up with one year where we offer very little biology, what would I do with my biology teachers that year, and of course I've got a year then where I've got a heavy demand on physics teachers and I don't have a staff to accommodate that either.

My lead teacher developed lab materials - the kids are in the lab a lot, doing fun-type things, but again the rigor of the math behind it doesn't seem to be there, and as a result he's really come to own this course, and he's quite resistant to changing what he designed. We've been talking about it for a few years, and I think he's going to come on board eventually.

A big change that's occurred is the technology, when I started it was dot timers and spring scales, and now we've got all the Vernier sensors and collecting data with them using LoggerPro, and we found that relative to the other methods, the kids are loving it.

They have a two-hour lab every week, so they get a very practical experience each week, and that's complemented by work in the classroom.

Another thing we're doing is flipping the classroom, providing short videos that the kids watch at night, rather than doing a reading, kids are not reading their textbook any longer, and then bring them in to partner up and have them work in small groups on projects or assignments.

Chemistry can be greatly enhanced with prior knowledge of physics, the modern concept of the atom, and energy levels, and wavelengths, lead to far better understanding.

What became abundantly clear to me as we went through our departmental review, and as a department we reached this conclusion, that we needed to go with PF, was the idea of abstraction relative to the students, and you know younger kids don't do as well with that abstraction as older kids do, and biology is no longer - identify this tree by its bark or leaf shape, it's more - what processes must occur within the organism for this to transpire. And because of that level of abstraction that's why I see the strength of moving to a PF program, because you can start with kids handling physical objects, then more to more abstraction in chemistry, then the greatest abstraction in biology.

Two hurdles: mechanically making the shift and keeping all of our teachers employed, and at the same time to move our admin to understand the benefits, because they look and see that things are working beautifully, yeah, until you know maybe it's not going as beautifully as we think.

P3: Origin: started in 2001 doing new conceptual phys class for freshmen using Hewitt and an in-house developed text. Had Honors and regular freshmen physics.

Impetus: headmaster's charge; school did not have a significant AP science offering. The PF program emerged when we did a departmental review looking for the best way to prepare students to do an AP science program, the notion that phys prepares for chem, and chem certainly prepares students much better for bio was the most compelling argument for doing it, but not everyone in the department was behind it, but in the end we're still using it and we've modified our physics offerings to make a better fit but for 14 years it’s going strong and giving us very good results.

Description of classes: What we have now is a regular freshmen-level physics class for students coming in who maybe haven't taken algebra 1, or they're repeating it. We have an honors physics class for freshmen who come in who are very strong in math, and it ends up being the same class we offer to Juniors with strong math skills. We also have a sophomore physics class for kids who come into the school who need to take physics but don't have strong math but we don't want to put them in with the freshmen because they can be overbearing. Reg fresh, H fresh (as rigorous as H junior-senior level), H for only Juniors and Seniors, Sophomore regular physics, AP Physics C, not all student have calculus before they take the class so we teach it.

It really is a good class for teaching them science skills: data collection, data manipulation, graphing, in all of our physics classes students use Mathematica, and also in H Chem. We also use excel as a department.

Honors Phys for freshmen is very much what you would expect in a junior-level physics course, heavy in algebra and trig with vector analysis; for the most part the H fresh and H junior Phys class are very comparable in terms of content: SAT II / NY Regents level.

Both courses make use of an inquiry approach, a lot of experimental design, you need to figure this out, here are the materials, make it happen. So, the inquiry approach is used more heavily and math more sophisticated certainly than it is in the regular conceptual-level class, which are much more in line with the type of math you'd find in Hewitt.

Inquiry more common in honors than in regular sections. Regular sections tend to be more cookbook: here’s the procedure, set it up, answer these questions, write the lab report. The honors sections have more inquiry by design.

Freshmen physics project: design a potato cannon, build it, fire it; honors class doesn't do that project, they do more straight labs

Motivation to do inquiry with H: more emphasis on experimental design, being a little more autonomous, building investigative and collaborative skills, and build subsequent lab skills.

Also, to help student think scientifically, ask questions scientifically, to learn skills to complete the activity.

And tie into analysis skills, make extensions: what is this going to mean outside the classroom, give an example outside of the classroom. Part of our inquiry/constructivist approach.

Maybe Bio teachers see the most benefit: we've had jumps in SAT II Bio scores, good jumps, in AP scores as well.

C3: I get students who had physics their first year. We also get a lot of new sophomores. Phys: foundation course where they do measurement and interpretation of data, as well as physics content.

PF wasn't much of a transition because I had done it before and I had been at a school that switch to PF, so to me it's all very natural.

Bio in 9 vs Phys in 9: preparation is very different. Kids now, they're very comfortable with numerical data, they are good at graphing, we can launch into gas laws more easily. We use Mathematica, they get experience with that. Kids get a solid foundation in a lot of the experimentation skills.

I can really build off of what they've done instead of having to start over. For ex: in phys they do a big unit on density and use that as a graphing example, so when I cover density in chem, I can go to higher-order content. More generally, we reinforce dimensional analysis, unit conversions, sig figs, they're all reinforced in physics and we touch on them in chemistry.

When students have bio in 9, they don't deal with numerical data as well, so I was doing a lot more instruction about how to manipulate numbers, and how to do the calculations, whereas when they have P9, they're already doing that with every experiment pretty much, so it gets them primed and ready to do more numerical stuff, and also abstract thinking that goes along with chemistry.

We do technique-type labs, like titration, where they have to learn how to do it, then we do some labs where they derive relationships for example gas laws, and then we do a project where students design their own experiment.

Description: chemistry Mythbusters project: divide into groups, they identify a myth to test, then develop the experiment, modeled after the show. Tied into the P9 b/c physics teachers use Mythbusters frequently.

Teaching chem to 9th: really challenging, not the right course for them. So abstract, freshmen really struggled with it, it was more of a physical science course, but it was hard to get into the more abstract concepts. 10th grade doesn't seem like that much different but it does make a difference.

Link between PF and inquiry: yes, but the reason is that in order to teach physics to 9, you have to reinvent the wheel a bit, it has to be a very hands-on, concrete experience; because that's the type of learner you have in the 9th grade. So, by design, the curriculum pushes you in the direction of being more experience-oriented, more open-ended in terms of what you do with the kids, so that leads you to the next level, the kids already have experience with it, they're good at it, so you keep going.

I haven't been at a school that did Bio in 9 for over 20 years

One thing that's important in PF curriculum is that the entire department has to buy into it, and that's one of the things that I'm fortunate to have here at Pomfret,

I work very closely with the physics teachers, we're constantly in each others' rooms, so there's a lot of P-C collaboration that happens both formally and informally;

so that the program really builds on itself, and the same is true with Bio, they are really clear about the skills they're looking for, and what they value coming out of the chem class, to make their class successful. You can't just do it by yourself in a vacuum, or it's going to look like you're just out there trying something different, and then everyone will get frustrated bc kids are learning what you want them to learn. The collaboration piece is so critical, and that's what makes this department special.

P4: Challenge: some students come to school after 9, changes sequence

Challenge: I had to get over the hurdle that you have to know lots of math to do physics, that was the lesson I learned, that you don't need a lot of math.

After teaching conceptual P9 for a couple of years, I felt Iike I understood the physics better.

I found it's great, appropriate material for freshmen. It's pretty intuitive, as long as you're not too focused on the math.

Everyone, for example has experienced gravity, people have a built-in intuition for basic physics, and when you study a course like P9, you're formalizing their understanding - which is already there but at a more gut level.

Also since you're not focused quite so much on the math, you end up doing a lot more interesting things in class - instead of wasting time deriving equations you're doing more hands-on stuff.

On the other side of the equation, it's a great time to introduce certain mathematical functions, and kids recognize the value of math. For example graphing - for a lot of kids it's a tedious exercise to keep your math teacher happy, but when you graph motion it actually tells a story and increases the value they see in studying math.

[Compare and contrast your approach to a given topic in physics for P11 vs P9] It could be that if I were teaching P11 now, my approach - it would be hard to forget for a moment my approach is more of a conceptual physics approach now - I think when I had been teaching P11, my immediate approach would have been to start doing FBDs and trig, components of forces, and attack it that way, whereas I think with P9, I would have kids think about: what is a force? Give an example of an object on a table, start to ask questions about what forces might be on it, and that's where they might start thinking about force having direction, then throw some numbers in from there. And whether you want to then put the table on an incline - that might be something you would do but only once they're more comfortable with addition of forces.

[Approach to lab work] A lot lab work is sort of cookbook labs - you get a set of instructions, you do what you're told, you write up a report and give it to your teacher, with P9 there's a lot less of that kind of cookbook type of lab work, and that translates to Biology - I've gotten away from cookbook labs there too.

[Projects, group work] P9 does some projects: classic egg drop contest, but it's blossomed, the kids spend several weeks on it. That project has become a stand-by in P9. Aluminum foil boats, build a boat that will float the most marbles, kids aren't given a lot of instruction, it's following the section on buoyancy. Topic-by-topic, there are shorter projects as well. With sound they get outside and get a map and stopwatch, told they need to figure out the speed of sound. Another, the kids have a water balloon launcher, and they have to work out a solution and try to hit their teacher.

In terms of the sequence, the way the material builds - as a bio teacher, I taught bio to sophomores, now I teach it to juniors, and there's a big difference in what you can do - there's a lot of maturing that goes on, so that's one of the benefits of PF is for biology teachers and biology programs - we teach a more sophisticated program.

And all the bio kids have all had chemistry, so literally spend no time going over chemistry, there's no need to. So the bio program benefits from PF,

and now we have more kids taking AP courses (phys, bio, chem), and also some shorter elective, but we have more kids taking four years of science, who I doubt would if they hadn't started out in P9 as freshmen.

Challenge: textbook momentum has a lot to do with it, and there is an awkward moment where you have a big wave of chemistry, and not enough chemistry teachers, so we had to teach out of area to cover the transition.

C4: My best perspective on PF is of my chemistry students, coming up from P9.

I think fundamentally, when they come to chemistry, they're in much better shape to deal with the chemistry concepts, chemistry deals with things that are incredibly small and hard to see, feel, and touch, so the kids have had a lot of exposure to a lot of the forces that are involved in chemistry but on a bigger scale so they can better understand it when they're doing it on a small scale, so I'm a fan from a chemistry teacher's standpoint, of PF.

I also understand from the other biology teachers, that there's an enormous amount of chemistry in modern biology classes, much more than when I took it in high school. The chemistry background that the kids have aids them tremendously in biology class as well.

[P9 before Chem] Chemistry is a different class, we still try to have a lot of hands-on, but there's a tremendous amount of material to cover, and there's probably quite a bit more discussion and lecture time than there is in P9. One of the things that I find very helpful is that they have a very good understanding of the fundamentals of a wide variety of forces and they understand already about mass, and about electric forces and things that have a real bearing in understanding chemistry: electrons, what forces hold together atoms. That's just a given at the beginning of the year, so I don’t have to spend a lot of time on that, I can spend more time talking about how those forces influence different things. Again, they're on scales that are hard to see, and it's nice for them to have knowledge in scales that they can see and understand.

[Lab work in Chem] We double-block lab periods in all our science courses.

We try to do demonstrations but don't do as much as in Physics. But our labs are geared to reinforce whatever we're learning, and we have a number of pretty good ones, a number that are not necessarily strict chemical experiments but more fun, that can tie into chemistry somehow, but most of them are serious chem labs. Labs are more directed than they are in physics.

P5: Origin: In 92, we taught a class for 9 that the school had made up, a physical science, BCP. Prior system, 60% of students took physics. In 92, we decided to reorganize things, make 3 years of science mandatory, and since we were thinking about that we looked at changing the order around.

We really became convinced that teaching P9 was the best idea because it was much less abstract, and we decided that we wanted to have chemistry come before biology because so much biology is really bio-chemistry, so we switched everything up.

Teach BCP, honors levels as well, electives in 12.

My story is: I absolutely love it, I came from teaching in traditional program, I think kids who are not likely to become engineers or scientists, the science they need to be scientifically literate, the physics can be taught without all the math that we used to think they had to have,

So it works perfectly in ninth grade, and absolutely everything I do, they can experience, see things move, take videos of things, for electricity they can play with the circuits, if it's light they can play with the mirrors, they can absolutely see hear and experience and understand everything we do, they don't X without the math

Chemistry comes next, which is more abstract than physics, but still doesn't need that much math, then chemistry after that, and these days there's so much chemistry, and if you have a year of chemistry you can move right into it, and

For our students who aren't likely to be science majors in college, they have a good background in the three basic sciences, and for our kids who want to go on into engineering of physics, they take our AP Physics C senior year, and they're really well prepared.

Transition: I had to be willing to do less math. When teaching to Juniors, every student was in Alg 2, so they understood vectors, they were more confident, so I had to be willing to do a lot of things without the math, or teach the math myself. In sound and waves we work with the dB system, needs logarithms, so I teach them that, as well as inverse functions earlier in the year.

It's hard for me to distinguish because we simultaneously switched to a block schedule, which allows you to do a lot of things you couldn't do otherwise. It's really good for 9th graders.

I barely lecture at all. That's one of the other changes over the last 10-15 years, I went to a flipped classroom approach about two years ago, so I mainly have assignments that are watching youtube videos I've created, or other things, analyzing data, for homework, and almost all the problem solving happens in the classroom, where I can be there and help, which is really where the ninth graders need the most help.

I do lots of demonstrations. Every class is lab work and demonstrations.

I still teach an AP Physics C every year, they're all in BC Calculus.

[P9 vs P9H] Regular class does a fair amount of problem solving, but other than trig, it's really just rearranging equations. The regular class does less depth - H does more mathematical and computational programming, I do some python programming with the H class. For the regular class we use more Logger Pro, where we use more excel in H. There's something too "black box" about logger pro for the H class.

I expect H kids to design everything on their own, I lead the regular kids up to it a bit. Pretty much the difference is that the H kids are better abstract thinkers, so I can do more abstract modeling, synthesizing. But the content isn't that much different.

I can't just throw the kids into this right away because of the culture of the middle school - there is an 8th grade IPS class, very structured and the kids come to me with good lab skills, but little sense of how to do an experiment where you're told - just investigate.

One of the biggest goals of P9 is for students to have fun and enjoy science, and I think when I started teaching 25 years ago, I wanted everyone to be an amazing physicist. Now I feel like the kids in my AP physics class, they've already made a decision, what they want to do, they need to be pushed hard, but my 9th graders, I want them to enjoy the process, and understand something about critical thinking and the scientific process, and so much of that is thinking about how you understand things, about how a pendulum works - by the time I get to that they're used to it, but it takes them a while. But I'd say it's big part of my teaching.

Every day they're doing something hands-on, although it's not always as formal as them designing their own investigation, but I'd say once a week. I'm a fan of modeling from ASU, and

I work with Vernier sensors and run workshops with them. We do a lot of things that are open-ended investigations.

In the fall, they do a physics of sports project, they research and do a presentation to their class. Then after studying motion they do mousetrap cars. They do a current event science chat, and a photo contest. Many long-term projects, make a music instrument.

[PF and Inquiry] I don't know, because it's all tied up with what I think is important to teach, and I guess I became convinced that PF is important, and I think project-basis is important. I teach AP Physics C, and because of the curriculum, I don't do any projects at all - lots of problem solving, lot of labs, but only one project.

I have been here a long time, and the people who are in the department, we all agree that this is what we think is important, so it's our science department that has a very hands-on model - AP Chem , AP Bio would say the same thing, not too many projects in those classes, but our 9, 10, 11, we do a lot of that.

So I think that P9 gets kids that, but you could do it with or without, but Biology has much more biochemistry, and has now become more abstract (or really always was), but I think ninth graders for the most part aren't yet really all abstract thinkers, but the accessibility of physics phenomena - they can see, observe, and feel these things - that's not true of chemical bonds, and it's not true of so much of what they do in biology, so I try to cover things in P9 that they can experience, and I try to make it like that, because chem and bio teachers try to do it, but at a certain extent they can't experience chemical bonds.

The most challenging concepts for my ninth graders are conservation of energy and conservation of momentum, and I would argue that part of the reason is because those are more abstract concepts. They can memorize formulas and solve problems, but to really understand conservation of energy and conservation of momentum, it's harder because it's more abstract, not every 14 year old is an abstract thinker.

C5: Since I've been here, physics has always been the 9th grade course, and that's different than other schools.

My involvement is, I teach chemistry, and after they do biology

[PF vs Trad] Each approach helped chemistry in different ways. When it was B9, they had to teach them a lot of chem for the biology, so that was an additional background, but now with P9, they're teaching them dimensional analysis, potential and kinetic energy, in other words the background is different, but probably about the same in terms of what I get from them.

Probably my biggest comment on PF is that it's incredibly useful for the Biology - I don't know how you could teach Biology anymore without having chemistry, and a lot of times chem-bio is like two years of the same class - everything I teach them they're going to use next year in biology. So again, whether it's physics or biology first, either one helps me, but I think it's the biology that really benefits

[How PF changes teaching in Chem] there are certain things when they had bio first - some organic chemistry, ionic and covalent bonding, that they came already aware of, and I just had to do a brief review, and I lost that, but now, with them having P9, there are a lot of other subjects, that I only have to do brief review: of course the math, but also energy and other things.

I have to do a lot less math.

When kids hit chemistry or physics, it's their first tough subject, and when they had biology first, then chemistry, I always had a number of kids crying and upset after the first test, because it was the first really difficult test they'd ever experienced, but now that they have P9, the teachers get them prepared so they're used to it.

Again, they have a better math background, and physics is more fundamental, biology is so much more specific things, biology has a lot more memorization, especially if you haven't had chemistry, whereas physics is more learning general concepts, and it allows us to do more - like we have a unit on quantum theory - and them having had physics definitely helps us with the background in that, and also like thermodynamics and stuff like that.

[Better for learning chem] I really like PF but it's really more for the biology - the biology teacher said they spend about a third of the year teaching chemistry, so this is an improvement.

[Lab work] no difference with PF, but they get a great lab basis in 8th grade

[Projects] One thing, I've been flipping the classroom. Traditionally, kids would come in and we'd do a lecture with a powerpoint, then they'd go home and work problems or something, but now I've been recording my lectures with me writing on my powerpoint so they can hear my voice and see my writing, and they do that for homework, and so when they come in to class, there's more time for lab and group work and stuff like that. That started this year

But I've always done a project that lasts a couple of months. One project I've been doing recently, starts with a big list of topics, like fMRI, or local climate change, or they can come up with their own, they research it, write a paper, create a digital product like a screencast or a powerpoint, that's a huge one they like, they find something they're interested in, and this is a group project

Benefits of flipping the classroom - I never had much trouble with classroom management before, but now there's none, and also it's one of the only things I've ever tried that looks like I'm going to get more time out of it - I'm sure you know, time is always the issue, and this is actually going to give more time, time for extra labs, time to cover more subjects, time for more inquiry labs, things like that

For inquiry, mostly I've done simple things, like you have to figure out percent composition of sugar in bubble gum and water in popcorn, and you have a balance and a microwave, and a bunch of gum and popcorn, and they have to figure out how to do it on their own, and I've done some inquiry labs with density - I'm hoping to get much more into this, time is always such a limiting factor, and this is something that might actually give me more time.

The thing is - the physics for the regular students (regular vs honors) has a lot less math, so when I see the P9 - again for the H students the math isn't that different - but my feeling is that it doesn't hurt it that much, it's more conceptual.

Challenge: physics teachers all revolted to the idea of PF, and other teachers too because they didn't want to teach biology. Logistically it's difficult because you've got all these biology teachers, and not that many physics teachers

P6: Sequence: ninth grade is CP, sophomore year is chemistry, junior year biology, and typically senior year is an AP class, or environmental science

Every student takes physics in 9th grade

It's a private school, so it's easy to do this, and the headmaster had a lot of confidence in me, and told me to do what I thought was best. I'd been teaching physics at several schools before here, and was convinced that was the way to go. It was an easy sell to the administration, and

the biology teachers really preferred to have students with a year of chemistry first, so they were behind it,

and we have the personnel in our department - I think there are four of us who have taught year-long courses in physics, and three of us who have taught year-long courses in chemistry, and three of us who have taught year-long courses in biology, so we all know each of those disciplines, and chemistry people know what we will do to prepare the students for that, so the department's very capable of that sequence and that's definitely what we prefer.

In the transition I don't recall any problems at all, we had our biology teacher that year retired, so we replaced that person with another physics person, who could do both, so really we had no problems at all.

[How does P9 compare to P11?] Two of us who teach P9 have had a modeling course, so we do a lot of hands-on, inquiry methods, and we extend that for the seniors as well, a lot of group work, white boarding, so there's not a huge difference in how we would teach it to the seniors and juniors.

We change the topics we teach in P9 from year to year, a few years we did almost no mechanics - we did solids, liquids, gases, optics, electricity and sound, so we did almost no mechanics for about two years in that ninth grade class. We now currently do a hybrid of that - we decided we do need to do Newton's Laws - because forces are important in bonding in chemistry and even in biology. So we do a little bit of mechanics in P9 but we don't do all of it - a small amount of kinematics, Newton's Laws, Energy, then we do Waves and Electricity.

Then the senior Honors Physics is stuffed with mechanics - kinematics, motion in 1 and 2 dimensions, Newton's Laws, Energy, Momentum, circular motion, rotational motion, gravitational forces. So, it's a traditional mechanics class, whereas P9 is a hybrid.

In P9 we do an extended project on Energy, we give them 8 different alternative forms of Energy - wind, solar, nuclear, fuel cells, biofuels, and they have projects in which they have to do research and then it's like a debate, we have them present support of the particular thing they studied, and there's a committee, and we're looking at economic issues, environmental issues, political issues, so we do a project that takes about two weeks in conjunction with a chapter on Energy.

They do that project in pairs, I have a movement where everybody is matched up with everybody else at least once, and we do problem solving in groups, they turn in their answers online through a clicker system, so I can see as they're working who's getting it right and who's getting it wrong, and if somebody is not getting the right answer, I can go specifically to student A, who got it right, and ask them to go help another group. So there's some accountability, but they do a lot of group work together so they can explain things to each other and bounce ideas back. I get immediate feedback through the clicker system.

Modeling is a great thing, it started at ASU. You'll start with a concept and start asking questions, like constant velocity motion - what do you observe about this car - is it speeding up or slowing down - how can we find that out? We'll start with a lot of questions, how can we figure out answers to these? And then after we've done some lab work, we'll start debriefing, and say, what conclusions can we make, and how should we define velocity vs speed, distance vs displacement. We start with a lot of concepts, it's not as much of a traditional lecture, we began by asking questions, and planning out what things we need to consider in designing experiments, then we go do that.

Definitely a lot more math for seniors, and at a faster pace,

they had a lot of background with the ninth grade class to begin with, in terms of terminology, and skills in the lab, how to make graphs, find direct relationships, find equations from graphs. It's definitely a faster pace for the seniors. We use trig, which we don't do with P9, it could easily be AP Physics B, in a few years, we'll probably make the H P11 AP B, but we also have AP C, which is calculus based.

We do modeling 2 or 3 days a week, we also do a lot of virtual labs and simulations from PHET, we have a great video library, video encyclopedia of physics - we show them something at least 3 days a week if not more. It's not simply a lecture class at all.

[Approach to changing curriculum of P9] There are a lot of topics in physics, and you can't simply cover them every year, so we take the position that we have two years to train them, so to speak, so we decided we'd like them to learn some electricity, some optics, some sound, EM waves, a lot of our kids will go on to major in science in college, and they've have a better math background by the time they’ve become a senior, so we can make it very close to a college level course - so we'd rather do that than just repeating the senior year the same topics we did in P9.

So we're trying to cover as many topics as we can, but we also think for many students, optics and sound, a little EM, turbines, things they'll learn in the Energy unit, that's probably a little more interesting to them than getting into the heavy math that you'd have in mechanics.

We are in an association with other schools, and some have come to us and taken our model as their model, so I think we've helped spread the word for a number of years, even our rivals are doing PF now, so we're pleased about that.

C6: I teach the sophomore level course, the students have a year of physics, then come and take chemistry, and then on to biology, then some choices after that.

[PF vs Trad] Typically it didn't change much of what I did in my classroom. The school I was at before was where I started, so I was figuring things out as I went along anyway, not paying much attention to how what I taught fit into the greater curriculum, I wasn't paying as close attention there as much as I do at my school now.

I do like the exposure to certain topics that fit well into chem, I like that they've seen that before they've come to my class, that there's more of that than I would say with biology in ninth. I would say, a little bit of the concept of charge, a little about energy, and conservation and flow, and some of the basic problem solving skills, physics and chemistry can have more mathematical problems where you don't see that as much in biology.

I would say that students are probably more used to doing hands-on labs coming from physics, although I know that can vary depending on how the course is taught. For a brief while the physics teachers were using a modeling approach, but

The chemistry course for the sophomores is pretty modeling-heavy, if you're familiar with that.

So, the idea is creating a storyline of matter, focusing on getting down to the particle level, focusing on the idea that everything is made of particles first, then adding on features, characteristics to those particles, how they interact with each other, charge, what they're made of, etc. As we go through the course of the year, trying to base it on empirical evidence as opposed to - today we're gonna learn about subatomic particles and I've got this nice powerpoint and we're going to take some notes. We're trying to build that more step by step, intuitively. That's probably not the best explanation.

It does impact lab work, in that our labs in the beginning tend to be simpler in that we're not going to give them a list of recipe steps to follow, we can try to focus on a simple question, like the mass of a system before and after, and change the system in a variety of ways, simple, concrete ways so the students are more involved in making predictions, and interpreting what they've seen, because it's not an elaborate system where they don't understand all the moving parts.

I feel like we do smaller, more frequent labs. The goal was to spend more time on pre-lab and post-lab discussion, so that they get more out of them. Over the course of the year we build up to more complicated labs, but ideally still with the idea that students understand what they're doing as opposed to just following a series of steps. I've taught that way as well, that works fine too, but I feel like students are more engaged with this approach.

I shifted to this approach in 2009, after I went to a summer workshop. We made some changes that year, then the other teachers who I share the chemistry classes with took it in 2010, so that we could more fully implement things. So three years, still pretty early on, figuring out how we can make it apply to our students and get the most out of it.

For now the modeling is mostly with us in chemistry, it started with a physics teacher, she has since left, and the other teachers who teach P9 don't do the modeling, I think they do bits and pieces of it, but they didn't embrace it quite as fully. So our freshmen probably have more of a traditional approach to teaching. And the biology teachers don't do any modeling, our senior physics course uses some. But I think we're gradually getting more support and interest from our other colleagues.

The course if very group-work heavy. Student spend a lot of time either with their lab group, who they do pre-lab, post-lab, and presentation with, they also do a lot of problem solving in that group, and a lot of presenting homework problems and lab results in that group. Very group-work heavy.

We haven't brought in any longer-term projects yet, but it's something we talk about how to fit in, but no.

The chemistry teachers appreciate them having physics before they get to our class. The biology teachers are very pleased with their position in the sequence, where they don't have to explain what a chemical reaction is, or what a molecule is, they probably have to review it, but these are things the students have already seen and know, so they can go into the more molecular part of biology, which is huge, without having to do a lot of pre-teaching.

We haven't really - we've been doing this for 22 years, I hadn't realized we started PF that early. For us, it's sort of become the norm, even though we know that a lot of other schools around don't do it that way.

P7: In P9, obviously we have to teach a course that is lighter on math than it would be if we were teaching it later. Most of my students are in algebra 1, we split it up based on math ability, but in either case, we do less math. We do some trig, but no calculus of course.

So, there are some limits to what we can teach in physics, but for freshmen who are being exposed to their first upper school science course, I find that it really isn't that limiting to not have the advanced math. We spend a lot of time in P9 learning by doing experiments, demonstrations, hands-on things, and kids are able to visualize what's going on, they're able to deal with it, even with their lower-level math, in meaningful ways, and get a lot out of the course.

[hands-on activities] I learned early on that the best way to engage students is not by standing up in front and lecturing to them, that it's a much more enjoyable and more effective experience for them to learn by doing things themselves - posing questions, trying to think their way through.

For example, we do simple things like we're told the value of "g" but figuring it out on your own is a different matter, the students develop multiple methods of determining that in the lab. I also have some particular labs that I like to do - a long series of things like that, I try to have something every day where the kids are seeing and experiencing.

And today the students' ability to use technology to come up with new ways of solving things - for example we had a speed of sound lab and a student modified the procedure to record the sound rather than use a stopwatch.

C7: Middle school they have a lower-level PS in 6, lower-level life science in 7, earth science or chemistry through earth science in 8, then as freshmen, conceptual physics, tenth grade chemistry with me, then 11th biology, then electives and AP courses.

I was not teaching high-school level before that, but it probably helps that I am a physical chemistry background, so when I'm teaching a sophomore level chemistry class I'm very much taking it from the perspective of fundamental chemical interactions, focusing on potential energy created by separation of nucleus from electron, and how light interacts with atoms.

So all of those things make it crucial - I'm not sure how I would have done it if we didn't have a PF program, because the physics teacher leads into exactly what I'm going to be talking about starting in the fall. So for me it's crucial, and obviously as a physical chemist, focusing on those basics is what's going to lead them to be successful, whether in my class or in the biology class the next year.

All of this has come about because we didn't understand the chemistry of biological systems fifty years ago when we put in this order of BCP, now that we know, it's kind of silly not to teach chemistry before biology, and in that respect, you know, chemistry is the central science, so physics should be taught first to get the fundamentals.

The broad concepts of macro-scale potential and kinetic energy is really something I draw upon in my chemistry class, this idea of KE is energy of motion, it hold true in chemistry, but instead of KE of a macroscopic object, we're taking about the motion of atoms and molecules, and then when we talk about PE and heat, I refer all the time to what they did last year, if in physics you're thinking about a ball rolling down a hill, with PE being the energy of position. And if you think of an electron that's further from the nucleus, just like there's a gravitational force pulling the ball down the hill, we've got the coulomb force on the electron. So that's a huge connection that I make, and it takes a long time, but we continuously come back to it.

I think that because physics is macro-scale, and it's easy to visualize, it can help make that connection to something that's atomic-scale. The students have a hard time with atomic scale because they can't visualize it. If they can make that connection, of the electron like a ball at the top of a hill - and when we talk about how light interacts with atoms, the physics teacher covers the basics of light, frequency, wavelength, how color happens, so when I get them they at least have the idea that light carries energy, that it has a particular energy that depends on its wavelength and frequency, so when they think about providing energy to move the ball back up the hill, you have to provide energy to move the electron away from the nucleus. So now we're not talking about mechanical energy but EM radiation to move the electron.

I don't think it's redundant at all because the only thing that gets repeated or reviewed is specifics about light, and I usually don't have to cover it very long, just the understanding that light is packets of energy, it's taking the same ideas and translating them from a macroscopic scale to an atomic scale.

Approach to lab work is evolving. I don't do a ton of lab work in the beginning, the first quarter, we do a lot more at the end of the first semester and into the second semester, and I know a lot of people think if you're taking a science you should do experimentation, but I don't know, I was a computationalist for my PhD, so maybe that's why I don't think it's as crucial as some people do, to be physically working with chemicals, but I think it's more important to give them a strong basis in the concepts at the beginning, the first semester is very much about PE and KE in atoms, how light interacts with atoms, then we move into bonding, we're still kind of talking about energy, but bonds forming in relation to the energy of the second semester.

In the second quarter I move into doing more calculations, so by the end of the first semester, so they have basics of concepts and basics of calculations, so in the second semester we can move more into doing stuff, we talk about solutions and molarity, and stoich using molarity, and ideal gas law, and solution chemistry, and redox, acid-base, so for me the lab stuff comes from how I've structured my course. Labs are weighted to the second semester.

This is a private school and I have a lot of autonomy to decide how I want to do stuff.

We do a lot of individual and group worksheets and practice sheets and stuff like that, but I don't do any projects, and maybe it's because I'm new and I'm trying to get stuff in, but we don't do any projects. We do one non-standard open-ended lab. And measurements so they understand the importance of sig figs, that's not exactly a lab.

I'm completely biased being a physical chemist, but a lot of my training as a teacher came from one of the professors I taught for, he was a biochemist, and had the approach of starting with the fundamentals. To me, it's all about coulomb's law driving chemical reactions, it's all about the electrons.

I wonder how that would work if you had a teacher that wasn't a physical chemist, maybe this is irrelevant in public schools because they only have bachelor's degrees anyways, maybe it doesn’t really matter, but I think there may be something to the fact that I have a PhD, in physical chemistry, and that facilitates the transition from physics to chemistry better than someone who only has a bachelor's degree or maybe has an advanced degree in some other area of chemistry. Maybe they'd be less willing to embrace it.

P8: Parent complaints, "too hard", going in with judgments about how it's going to be bad

Waves (sound, light) in 1st Q: reason: it's the material they have the easiest time with, least stress. To 9th grade is a big transition to more abstract thinking (less memorization & regurgitation). PF forces them to make that transition earlier, which is a benefit to them in the long run, but poses challenges to them as well.

Focusing on broad concepts, not just how do you solve a projectile motion, but learning how you solve problems more generally, not just in physics but in their education as a whole

PF taught me to be a lot more deliberate and consistent with the students in telling them that they are going through a change. We are trying to figure out a way to tell freshmen that their brain is learning how to work differently and you need to have some patience with it but it's going to benefit you in the long run.

Start with Waves, feel comfortable with that, start introducing math concepts with waves, looking at proportionality. Then look at it graphically.

Have to be in contact with parents regarding transition challenges

Concrete strategies to use across the board: overarching strategies, problem-solving approaches

Different in P9 vs trad: ex: treatment of vectors is different for levels of P9 (math level), same with forces, projectile motion, electrostatics, etc

[differences between trad and PF in terms of projects or group work]: not a lot of differences; 9th graders love working in groups, have arranged classroom in 3-student pods, they bond and work with their pod.

Group work is better than it was than in 11 or 12 - because by then they're more rigid in how they want to learn, and less moldable; P9 more enthusiastic about projects; 11 or 12 less; 9th grade loves egg drop project.

[Approach to projects and design: different before/after switch to PF?] I'd say about the same.

But our school does a lot of labs and a lot of projects.

Blocked out 90 minutes per class gives time for labs and project. Probably about the same for our school, but that's because we've always had a focus on lots of labs.

Description of Project: Egg Drop. At end of momentum chapter. They come up with their own contraption, within dimensions and extra points for non-traditional packing materials.

Seismic wave project: investigation of seismic waves, different regions of the earth, chose any method of presentation for the project (powerpoint, video, etc)

C8: We began to investigate in 96-98, began conversion in 99-00, so we've been doing PF for 13 years.

Someone else was department chair at time, but the entire department was involved in the discussion and the decision.

The transition was great. Once we decided that it was for us - and we interviewed a number of schools that had converted, and we tried to find comparable schools, we're a girls' college prep school, and except for one school, they all loved it.

The one school where they had some misgivings it was because the physics teacher was used to teaching juniors and seniors and couldn't figure out how to do it with less mathematics for the ninth graders.

So based on our research, and our own sense that this was probably the right thing to do, we went ahead and began to lay the groundwork - and that took us a few years.

The biggest hurdle for us was the fact that since we had normally taught biology to ninth graders in sort of a traditional US program, BCP, we had bio teachers that weren't going to be teaching bio for a few years, and needed physics teachers, so that was the biggest hurdle we had to overcome. We were able to get one person to sort of become a physics teacher, with help, one person decided to retire at that point - a biology teacher - for a lot of reasons but this was one of many things, so for the first couple of years we were still teaching physics to ninth graders, but were still finishing out the remaining who'd had biology in ninth grade. We got lucky because the teacher we hired to replace the retiring teacher was only here for the duration of the change because her husband was stationed here. So we kind of fell into this solution to the problem. That worked out beautifully and we've never looked back, we love it.

Speaking as someone who teaches chemistry that follows P9, I found that there were some topics in chemistry that I always sort of pulled my hair trying to get the kids to understand, not the least of which was that there is energy stored in chemical bonds, and you try to explain gravitational PE, they haven't had that yet, so that didn’t make a whole lot of sense to them, but after P9, not only did they understand PE and KE, but they had already seen PE, both gravitational and electric, elastic PE - which is a great analogy for energy stored in chemical bonds - and so, that whole part of chemistry became much easier for us to teach.

And the long-term fallout is that we are now teaching a truly modern biology course, it is largely molecular biology, because of course that's where biology is at this point, unlike the biology I had when I was in school, which was really not molecular.

So we find the progression from the physics which is - in many ways less abstract, and they can see everyday examples of it, moving from there to chemistry, which deals with smaller molecules, then to biology which deals with the larger and more complex molecules, is sort of a natural progression that works really well for us.

I make a lot of reference to Coulomb's law, when we're talking about charges, and ions, and intermolecular forces, and of course the students understand Coulomb's law because they had it in ninth grade, so that works out really well.

Our students generally take algebra in 8, and geometry in 9, and when they were taking geometry and biology in ninth grade, their algebraic skills got kind of left in the shuffle, and now they've got the alg 1 in 8, they're getting some simple reinforcement of algebra skills in physics in 9, so when they get to chemistry in 10 they're not quite so math-averse as they were in previous years because they've kept up that more quantitative math as well as the geometry they're doing in ninth grade.

I do plan with their math teacher. For example, when I'm teaching logarithms when we get to pH in the spring semester, the math teacher has just gone over logs in alg 2 in tenth grade. And the P9 teachers try to plan with the math 9 teachers to try to take advantage of any cross-fertilization we can get in those courses.

In all of our courses we try to do a lot of inquiry. Students don't go into the lab knowing the answer to the question - not to say that scientists don't know the answer, but as beginners they don't know the answer, they don't know what to expect, it's not simply confirmation of something they read in the textbook. We do what we call informal lab activities, where we provide a lot of the structure and they are filling in the tables and doing some computations and answering some questions, and then once a quarter, at least once - teachers have students write a formal lab report, where they create much more of the structure themselves, and it's usually a bigger problem.

In one of the quarters in chem, we have students look at the density of carbon family elements, and plot that against atomic number, and make some predictions about two of the elements in the family based on the other three. So they don't really know what they're supposed to get. We're trying to model the thinking that Mendeleyev had when he was able to make some predictions. Fourth quarter of this year we added a new activity where the students had lot of solutions of salts that they could use, and we had them make hydrogels, from biological samples, and see which of the metal ions formed the best crosslinks. And they had to design how they were going to decide, which proper link for the hydrogel. So the formal lab reports have to do with these bigger activities, where the students do some of their own experimental design, come up with how they're going to conduct the experiment - sometimes we have to give them some guidance, but there's always some aspect that they're asked to design, do the analysis, and come up with their own discussion of their results.

To some extent the inquiry-based philosophy has been here as long as I have been. We've always tried to have them do some authentic experimental work. Not necessarily that the answers are unknown to science but that the answers are unknown to them, rather than the confirmation - this is what the book said and I see it happening.

One of the big experiments we do at the end of chemistry is that they have multiple brands of vinegar and they do a titration to ultimately figure out which is the best buy. So it's kind of a standard titration, it's not hard to neutralize acetic acid with NaOH, but we put this extra practical twist on it. This has been the theme of our work as long as I've been here.

I think that physics lends itself to a lot of laboratory work, probably even more than chem or bio does, they do lots of lab activities, so it's really enhanced the program.

When I first came to NCS, the graduation requirement was 1.5 y of science. The half year was a lab science, but on the science brains took chemistry and physics. Now we're a high-powered college prep school, and when I came in we changed that, now all students graduate with 3 years of science, and more that 60% have 4 or more years. We have lots of students who go into STEM fields, more and more engineering all the time.

I think probably the broadest impact of P9 is that students come out of that course believing they can do science, because it's so hands-on, and straight-forward, and so even though the chemistry is more abstract, they tend to think, yeah we can do this, we did physics we can do chem,

And definitely the biology has changed substantially. When we taught bio in 9 and we tried to show them the difference between a protein and a carbohydrate, and a fat, in terms of molecules, for them it was a bunch of C's and H's with lines, they didn't know one from the other. Then they would come in after that to chemistry saying that they hated chemistry even though they'd never taken chemistry, because it was such a mess to them. And now they're completely comfortable with difference types of molecules, they understand them, can tell the difference between them, they can really pick up on the differences.

And we're now teaching a truly modern biology course as opposed to a course that was largely non-molecular, because when you try to explain different shapes of proteins, it didn't make any sense, because they didn't know a H-bond from anything else, so we've been able to move to a biology course that focuses on what we now know about how those processes occur on a molecular level.

The hardest part for any school will be the need for more physics, less biology teachers during the crossover, and the physics teacher who is wedded to teaching it at a junior senior level with lots of math. They have to come back and focus on the concepts and drop the math.

Once you make the change, everyone else I've talked to really likes the order.

We've seen a drastic increase in the number of students taking science, some of it is our requirements, some is knowing colleges like to see three or more sciences, I don't know I can lay that to PF, it's a combination of that with all sorts of other things.

We've recently added more electives, including an engineering elective, and that's associated with PF.

P9: I did student teaching in PF, taught in a PF program, taught at college, now back in PF program.

9 is first year in which we track, we have honors and standard P9. Adv is honors. I teach the H sections, another teacher does the regular.

When I arrived, honors track was PCB, non-honors track was PBC. In discussions, I thought it didn't make any sense, and hinders movement from one track to another. This makes it difficult. As of 4 years ago, PCB regardless.

P9 H is not as different from P11 as you might think. I follow a pretty standard order, mechanics in fall, spring semester I do matter, then waves, including acoustics and optics, then EM, and finish with relativity. A difference is that in P9 I introduce them to trigonometry for the first time, in other words I show it before they see it in math, very basic right triangle trig, and I can't assume a great facility with algebra - although these are the honors students, so they've had Alg 1, honors, most of them, and most are in H geometry, but when I use the algebra, I'm certain to go slowly, narrate carefully what I'm doing, my reasoning, because they're algebra, although they've had it, most of the skills they need for my class, they're not entirely confident in them.

I have not taught the regular P9 here, but I did before. I took a similar approach, no trig then, at my current school, the non-honors class is very different than the H class, really because of the preference of both of us really, he prefers to teach a modeling approach, and I prefer a more traditional approach with a lot of flipping the classroom video technology. He spends virtually the entire year on mechanics, with a couple of weeks at the very end on waves.

We don't have lab periods, so I don’t have any double periods or anything like that, so the labs I do have to be confined to a 45 minute class, that obviously limits what I can do, and the labs are - I don't want to say cookbook, but there are some cookbook elements to it, I try to mix that with more open-ended sorts of things, and there might be outside of the classroom aspects as well, a lab that I do in acoustics - we're a laptop school, so the entire course is online - that acoustics lab, they're using a spectrum analyzer on their laptops to analyze tuning forks, but then I also ask some open-ended questions, like find something interesting to you, and analyze its spectrum.

At the ninth grade level not that much of them coming up with their own investigations. Most of the rest is guided. I also teach the AP Physics class, and that is much more open ended, I give them goals for the lab, but not usually the exact procedures they're going to follow to get to that goal.

Mostly they work with partners. Two things near the end of the year, we do a video project, where they make a video explaining some aspect of physics, so this can be a combination of live video they shoot of themselves, along with explanations and can include screencasting and voice-over, they can work alone or with a partner. They've seen a lot of modeling of that, I've made many videos myself. The other is that throughout the year I collect from them anything from home that breaks, a printer, a camera, a toaster, and they're going to throw it away, I have them bring it in to school, then through the year we develop a mountain of stuff, then we spend a solid week in the spring, after EM, taking it apart, to understand how a toaster works, you have to understand basic circuitry, the bimetallic strip for the thermostat, IR radiation, or taking apart a camera. It's not an independent project because we're doing it all together. Look at heating elements, fuses. They have to be able to identify transformers, transistors, and know what they do.

P9 vs P12, part of the difference is time-related. I have a double period for my AP class, so I have the luxury of more open ended questions. For P9, with 45 minutes, there's less time. Also the age difference, I want to guide them a little more so they don't freak out about trying to come up with something on their own.

With P9, I feel like it gives an answer to "why do I have to know this" question about algebra and math. They're using it in the physics class kind of at the same time as they're learning about it in math. They're no wait - they're using it in their physics class right away.

So I work with the math teacher that teaches most of my students, to the extent we can, we will reference each other's curriculum. We can't re-sequence things, like I do trig before they get it. But having seen it with me makes it easier in their math class, that repetition and relevance - that it's being used not just in the math class. I think it make it all more relevant and helps them retain it.

By the same token I refer to their math class. When I have coordinated, I try to make sure we're using the same vocabulary.

We are a private school, so our admissions folks give tours to prospective parents, and most parents didn't have physics in ninth grade, so using math concurrently is an argument I make, and the logical argument with physics being the most fundamental, with dealing with concepts like energy, and electric fields, and forces, the basis of chemistry being the basis of modern biology - cell biology, microbiology, you really need to have a background in chemistry to understand modern biology.

P10: Let me go back to AAPT summer meeting, that summer Hewitt had just developed his conceptual physics course, and developed an adaptation of his program - which had been designed for non-science majors - for high school, and it required no math beyond what they normally have in 8th grade, so there would be no reason this could not be taught at 9, and he pointed out how physics is the most foundationally and fundamentally important science, and it should be taught before chemistry, then the chem should now precede biology, because so much biology was chemistry-based. This was back in 1989.

At that time I was teaching an energy-focused physical science course I had developed myself, but I thought this guy has a point, and there's no reason I couldn't do a tradeoff, instead of teaching my course to teach his, so I went back to my upper school director and we talked about doing that but also encouraging students to take chem as sophomores.

Two years later, the US director said I think we're ready to move to make this the whole ninth grade - at that time I was doing it with only one of two section, the other was at that time an earth science course.

So we made the transition to BCP and its been that way ever since,

Except in 1994 I learned about the Active Physics program from Eisencraft at the NSTA meeting. I went up to him afterward to express my interest, and he contacted me and we started teaching Active Physics in 1994, and I've been teaching it ever since.

The transition was trading my ninth grade physical science for P9, but we still have the junior/senior physics course, we still offer that as an elective.

P9 vs P1112 is a lot more experiential, we do a lot of calculations using spreadsheets - I teach the students how to use spreadsheets as a calculation tool, and we get the equations from numerical results we get from experiments.

Active Physics has labs integrated, there are places I have my own version, but I've stayed true to the general scope: introduce the chapter challenge and the beginning of the chapter, I got through each of the sections, each starts with a what do you think question, then it's followed by what is now called "investigate" part which has questions which I would call guided inquiry, to learn about the subject matter raised in the what do you think question.

I like the alternative authentic assessment of doing a chapter challenge, because in this way you have students working in groups to solve what is close to a real-world problem - real-world in the sense that it doesn't have a single unique answer, hopefully we can avoid what I call the right answer syndrome.

I built-in 90 minutes of class period for the groups of students to work on their chapter challenge, you have to realize they've got lots of other commitments after school and its not really realistic to expect them to get together to do these projects outside of school because of the differences in their schedules.

I use the modeling of physics to teach physics.

Impact of PF: the mathematical sophistication in dealing with the mechanics part of physics is so different from P9, in P9 we don't get into the kinematics formulas specifically, so a lot of that is

The chemistry teachers are still pretty much in the same place, because it used to be BCP. The biology teacher is very enthusiastic about PF because he gets students with a lot more sophistication. All the biology teachers that have been here since we started PF have been very enthusiastic about it.

The educational philosophy of the school is supportive of inquiry. I'm not sure the extent it's being done in the chemistry course, we switched to a new schedule that has 5 terms in a year, and these courses are typically 3 of 5, so the teacher has had to rethink her curriculum to match with the new curriculum.

I know that the biology teacher is very heavily into projects, because he has students researching a topic that they then present to the class.

P11: We have on paper a two-year requirement, but everyone takes 3 years.

Physics is mostly 9, a few 10, some transfers.

When we first started doing it, scheduling became tough and my senior physics class got scattered.

I teach one Honors section of P9, in it we do a lot more math.

We use Hewitt's textbook for regular, but don't do everything in the book. Different text for Honors.

30 years ago I was at an AAPT meeting where Uri Haber-Schaim gave a talk proposing the idea of PF, and a bio teacher implemented and gave a talk about it at a bio teachers meeting, our bio teacher saw it and got excited, and I told him I'd heard of it, so he said let's do it.

It took - this was 20 years ago now - quite a while to convince higher-ups, and I don't know if it would have worked if it wasn't the two of us, but he was so excited.

What happens is that during the transition years, the students who took bio as freshmen are ready to take physics when they're older, meanwhile the next freshmen are taking physics and there's a great need for physics teachers and a smaller need for biology teachers. So the way we made it work was we had a bio teacher who learned to be a physics teacher for a few years, and once we got past the transition it was easier. He needed a lot of help but was enthusiastic enough to make it work.

I think the transition to younger students was something I hesitated about before we made the switch, I'd taught lots of different age groups, but never ninth grade. I did have experience teaching middle school.

The ninth grade kids are great, in a way they're more fun to work with than the older ones, because they still have more enthusiasm and curiosity about the natural world, the older students - even if they are curious it's not cool to display enthusiasm about it, and they're very concerned about how sophisticated they look.

P9 involves finding the right amount of math that the kids can handle. We use Hewitt's text, he tries to do physics without using math, but he really is using math, it bothers me the way he pretends not to use math but really is.

One of the arguments for doing PF is that the kids are either taking algebra concurrently or they've had it the year before, it should be fresh in their minds, and PF is a way for them to see an application of the math to the physical world.

For older kids, the algebra can be taken for granted, you can throw in trig and they may need a reminder. So in P9 I stay totally away from trig, and when it comes to algebra I do a lot of hand-holding, we have kids that are a little challenged when it comes to formulas, but they can be easier in physics.

One of the things I love about teaching is finding ways to communicate complicated ideas that I've learned in the past to a level that young people can understand and appreciate.

We do lots of labs. We have some extra lab time in the schedule. I try to have stuff every week.

When we first started doing PF, I was concerned about the kids who were taking Alg 1 concurrently, so I volunteered to teach a section of Alg 1 so I would get an idea of what they could do, and they could solve the really basic equation solving we do in physics, they can do by October - even Alg 1 gets to much deeper math than most first-year physics needs.

When you're doing intro physics, all the textbooks start with kinematics, and you're worrying about the distinction between velocity and acceleration - it really blows their minds, and if they're challenged by math that can be a tidal wave of information that bothers them, so we start in the middle of the book, we do sounds, waves, and light in the fall.

For waves, speed equals frequency times wavelength, that's about the only equation they have to worry about, not velocity or acceleration or time, all the stuff that gets complicated with kinematics, we wait until November to do that, do waves sound light before, which is great because there's lots of labs.

In the first week, I get out slinkies and have them doing experiments with waves, interference - these labs are more qualitative than mathematical, so it gets them started and they have fun with it, starts them out with a positive attitude.

I try to do as much lab work as possible, and when we're doing lab work I try to make it some kind of a puzzle to solve or some kind of an unknown that they're measuring. For example hook's law with springs, I give them an unknown and they have to figure out the mass of the unknown, and whoever gets closest gets a candy bar.

Not really any projects that last more than a week. At a boarding school, their time is highly structured.

No student-designed experiments. I usually arrange it so that they'll do it the way I want them to.

Approach to labs not that different in P9 vs P11. Coming into I wanted to make P9 as much as possible like it would have been for the older kids. Not to be watered down. So a lot of the labs that I do are the same as what I would have done with older kids.

We use Vernier probes fairly often in P9, I'd rather deal with something where the kids are measuring things directly, there's a black-box element to the probes, so I like them to do another similar measurement without the probes, then verify with the probes, it can take more measurements quickly.

We do have AP Physics C, with them I use the probes very frequently.

I don't think anyone, even very sophisticated people, can really understand the microscopic world until they understand the macroscopic - it's all an extension, by analogy often - if you're going to do ideal gases, first you imagine what a single particle would do, bouncing back and forth, and generalize from that to zillions of particles bouncing in three-dimensions, but you've got to have a good understanding of the big things before you can understand the little things.

The other issue is the number of topics one can go through in a year - it's never as many as we would like to. I think it's better to do fewer topics and have the students feel some confidence that they understand what it's about that to rush through and make sure you've covered everything.

That's one thing that's nice about teaching in the ninth grade because I'm not as worried about what they're going to do on an SAT II test, juniors and seniors are more worried about that.

I had the idea of starting the year with waves - I may have had that with an old PSSC physics, and I was looking back at an article by Haber-Schaim about developing the PSSC curriculum and the physics books that existed before that, which consisted of lists of assertions about the world and vocabulary to be memorized, without being engaged in the processes of physics. The goal of PSSC was to get kids closer to doing real physics.

The other people that teach physics, one was a chem teacher then we have the bio teacher. I've noticed that old bio teacher tends to stick to physics more like biology, which can be more vocabulary and descriptive than physics, so he was more interested in making sure the kids knew all the words and read all the pages in the book, but he was good with having them do experiments, then the old chem teacher always to my mind puts too much emphasis on physics as pre-chemistry, he's always interested in electrons, I want them to think about charge, it's something it doesn't matter if it's positive or negative, but he wants them to know about electrons from the start, and he has them use left-hand rules.