2016

Putting Physics First: Three Case Studies of High School Science Department and Course Sequence Reorganization

Douglas B. Larkin, *Montclair State University*

Putting Physics First: Three Case Studies of High School Science Department and Course Sequence Reorganization[1]

by Douglas B. Larkin, Montclair State University, Montclair, NJ

Abstract: This article examines the process of shifting to a "Physics First" sequence in science course offerings in three school districts in the United States. This curricular sequence reverses the more common U.S. high school sequence of biology/chemistry/physics, and has gained substantial support in the physics education community over the past few decades. Using qualitative case study methodology, the present study focuses on the lessons learned in three school districts that successfully rearranged their course offerings and made physics a ninth-grade subject for all of its students. Findings show that in all districts, the shift was undertaken to support student learning in mathematics and in future science learning. In every case, the coordination between ninth grade physics and ninth-grade algebra was much more difficult than expected. Also, during most transitions, the number of students taking biology dropped precipitously for a period of 1–2 years. Though there is shared agreement about Physics First as the realignment of the high school curricular sequence, there is less consensus about how such programs ought to be aligned with mathematics curricula. The article concludes with suggestions for sources of evidence in conducting effectiveness studies on the Physics First approach.

Keywords: physics, science curriculum, science departments, physics first

The history of education reform points to a need to understand the local contextual factors that support, hinder, and sustain efforts to improve learning in schools, and the field of science education in particular is filled with well-intentioned efforts to reform the teaching and learning of science that have ultimately had a limited short-term impact beyond a small percentage of classrooms (Cuban, 2013; DeBoer, 1991; Rudolph, 2002). Taking into account the classroom, school, and district organizations as they relate to curricular reforms is therefore essential if the field of science education research is to improve science teaching and learning. The recent push towards coherence among the multiple layers of contemporary science education reform reflects this understanding (National Research Council, 2012).

---

[1] This article has been accepted for publication in School Science and Mathematics: http://onlinelibrary.wiley.com/doi/10.1111/ssm.12168/abstract and should be cited as: Larkin, D. B. (2016). Putting physics first: Three case studies of high school science department and course sequence reorganization *School Science & Mathematics, 116*(4), 225–235. doi: 10.1111/ssm.12168

The "Physics First" movement in the United States is an example of one such reform effort currently underway.[2] Physics First is best viewed as a loose coalition of scientists and educators who seek to place physics as the first curricular offering in high school science, and as a prerequisite to high school chemistry and biology. Though the idea of putting physics first in the high school science sequence has long historical roots (Sheppard & Robbins, 2009), its recent resurgence can be traced to the era of education reform ushered in during the mid-1980s by the "A Nation at Risk" report (United States National Commission on Excellence in Education, 1983) and the public support of physicists such as Leon Lederman, Uri Haber-Schaim, and others in the 1980s and 1990s (e.g. Haber-Schaim, 1984; Lederman, 1998). Advocacy for a Physics First approach within the science education community has been active now for decades (e.g. Bessin, 2007; Bybee & Gardner, 2006), yet firm agreement as to what "counts" as Physics First beyond a resequencing of high school science courses remains elusive. Furthermore, peer-reviewed empirical studies on efforts to enact this idea at the level of the department, school, and district level are scarce to non-existent.

As of 2009, approximately 82,000 students (4% of all physics students) in the U.S. were enrolled in a ninth-grade course described as Physics First (White & Tesfaye, 2010). Yet, the literature is largely silent on the nature and details of the school-level and district-level shifts necessary to effect such a change, as well as the ways in which Physics First is conceptualized and operationalized in these courses. In one mid-Atlantic U.S. state, a number of school districts have recently reconfigured their curricular sequence in high school science, making physics a ninth-grade subject. This situation offers the opportunity to investigate how the local

[2] Though technically not a proper noun, the phrase "Physics First" is capitalized throughout this paper for purposes of clarity.

contextual factors have influenced the adoption of this reform. Thus, the research questions to be addressed in this study are as follows: 1.) What are the different ways in which Physics First is conceptualized, operationalized and evaluated as a curricular change by school and district personnel? 2.) What are the local contextual factors (curricular, district, school, and classroom) that influence the adoption of a Physics First approach?

Theoretical Framework

This study is grounded in the belief that understanding leadership practices and practical wisdom at the district, school, and departmental levels is an important, necessary, and often neglected aspect of curricular reform efforts. Halverson's (2004) guidelines for the production of *phronetic narratives* serve as the theoretical framework for this study. A phronetic narrative begins with an artifact—in the cases examined here, the artifact is the Physics First transition schedule of each district—and seeks to uncover the practical wisdom embedded in that artifact. Halverson (2004) describes the importance of understanding artifacts as tools and products, noting, "Artifacts are the tools leaders use to establish structures for shaping social interactions, work practices, and learning in schools'' (p. 100).

In this study, Halverson's guidelines for the production of phronetic narratives are used to describe the practical wisdom reflected in the design of the shift to a Physics First curriculum across the school or district. Such an approach entails examining how the goals and strategies employed by those charged with stewardship over high school science curricula have affected the ways in which problems were set and ultimately solved. This analysis attends to both the affordances of the artifact—that is, what the shift to Physics First enabled the designers to do—as well as the constraints imposed by certain design choices. In order to facilitate future utility of this study for those considering similar shifts as those described here, the ‘‘lessons learned’’ from each district’s transition to Physics First are also shared.

Though this research takes no position on the desirability or effectiveness of rearranging the curricular sequence of high school science courses, it is relevant for this study to report participants’ views on the perceived benefits, drawbacks, and other consequences of these curricular shifts as elements of the data for contextual factor analysis.

Study Design

This research is a collective case study (Stake, 2000) of the high school physics programs operating in three school districts in a single U.S. state. The institutional, curricular, and pedagogical changes undertaken as a result of the decision to shift to a Physics First approach represent the boundaries of each case. The three districts include one large urban school district, one small urban district, and one mid-sized suburban district (see Table 1). At the time of this research, two of the sites had been using a Physics First approach for over five years, while the third had only completed the transition recently. These three sites were identified by requests made through professional networks within the state, and though they represent a cross-section of the different contexts for the Physics First approach, they are not intended to be a representative sample. Rather, the design of this study allows for maximizing the opportunity to learn from the research, as suggested by Stake (2006) in collective case study methodology. Pseudonyms are used for all names of people, institutions, and districts, and the names of physics curricula are not used in cases where they would lead to identification of individuals or districts.

(Insert Table 1 approximately here)

Data in this study was obtained primarily through the use of semi-structured interviews with at least two physics stakeholders in each district, which included one content supervisor and at least one teacher. Each interview lasted between 60 and 120 minutes, and a consistent interview protocol was used for each.[3] Other publicly available data, including course schedules and district demographic data, was also used to construct each case.

In the first stage of analysis, each of the interviews was transcribed and initially coded to identify elements that related to the two research questions,[4] and further analyzed to identify salient themes emerging from the multiple interviews that comprised each case. A narrative was then constructed for each case, and the three cases were then subjected to a cross-case analysis to identify commonalities and differences (Stake, 2006). A draft of each case was shared with the participants to verify the trustworthiness and authenticity of the narratives, and feedback from this process was incorporated into the final version.

To be clear, this is not an evaluation study of the effects of a Physics First approach, and there is no effort here to gather evidence for the effectiveness of the various outcomes sought by each district. However, the present study does report on some of the measures that the districts themselves were using to gauge the impact of Physics First, and the final section of this study reports on sources of evidence that future researchers may use toward this end.

Findings

The following sections comprise a set of case study narratives that describe the process of transitioning to a Physics First course sequence in each of the three districts in this study.

[3] Space limitations prevent reproducing the protocol here, but it is available by request from the author.
[4] Following the methodology of Stake (1994), data was coded as relating to each "issue" in the research questions. Therefore, any data relating to themes of "conceptualization of Physics First" (e.g. rationales, learning theories), "operationalization" (e.g. district and school structures, teaching and pedagogy), "evaluation," and "contextual factors" were all coded as such.

Attention is focused on each district's goals for this shift, as well as aspects of the context that supported or impeded change. Each case concludes with a brief discussion of the affordances and constraints of Physics First in the district, as well as some of the lessons learned, as reported by the participants in the research interviews.

Case #1: Riverton

The Riverton School District is a medium-sized, urban district, located within a large metropolitan area of the state. The demographics of the district in state reporting documents show that a majority of the students identify as Hispanic, nearly a quarter as African American, and the remainder as Middle Eastern, South Asian, and White. More than half of all students come from a household where the primary language is other than English. Over 80% of all students in the district qualify for free or reduced lunch.

The district's curriculum director had long felt that a ninth-grade physics program was desirable, but prior to the spring of 2008, there was little opportunity to create such a program, especially given the shortage of qualified physics teachers in the district. Up to that point, physics had primarily been taken by a limited number of students in the 11th or 12th grade. In the fall, a program known as the Science Initiative for Teaching (SIFT)[5] was just beginning at a nearby state university, supported by the largest teachers' union in the state and an array of corporate and foundational sponsors. In consultation with district administration, the Riverton district curriculum director made the decision to adopt the SIFT curriculum, and the district started planning for implementing the program in the following school year.

[5] This program name and acronym are both pseudonyms in order to maintain the anonymity promised to participants.

The SIFT program consisted of two main components. The first component of SIFT was a comprehensive curriculum that had been developed and field tested at a local high school for the past decade, and compiled as a series of slides to be used in conjunction with electronic whiteboards, class sets of personal response system units, and required laboratory materials. This three-year curriculum—with physics the first year, followed by chemistry then biology—is described in the supporting materials as based on the curricular content of the College Board's Advanced Placement (AP) courses. The intent of the SIFT developers was that students would be prepared to take an AP course in physics by the end of 10^{th} grade. The SIFT Physics course was taught primarily as a sequence of problem-based slides, which teachers could use as they wish. All of the course materials were freely available online for students, and curricular resources for teachers were provided free of charge on a password protected web site.

The second component involved working with previously certified teachers to attain certification in physics. Some of these teachers had a science background, but others were from fields such as social studies, English, and physical education. There were also some teachers already certified in physics who participated in the training in order to better understand the curriculum. A waiver from the state legislature had been granted to the local university to work with the SIFT program, offering an alternate route certification that included coursework in both content and pedagogy. A current district administrator for Riverton had recently observed some of the SIFT teacher certification classes, and reported that they were taught to teachers in the exact same manner as the teachers were expected to teach their own students. Most teachers who enrolled in the program earned physics certification in 18 months.

During the first year, Riverton enrolled a cohort of six teachers (most of whom possessed a previous certification in biology) from three of its high schools to be certified in physics through the SIFT program. The following year, the default science course for all of the ninth-graders in those schools was physics, and in 2010, as more teachers went through the SIFT physics certification program, the shift successively occurred in more schools. By 2013, the last of the schools had shifted their physics to ninth-grade. In this five year span, a total of 15 teachers were certified to teach physics, and beginning in the third year, a total of seven more teachers became certified in the chemistry track of the SIFT program as well. It is salient to note that the cost of this certification program has been and continues to be covered by the district, a significant investment by any measure.

When a school adopted Physics First in the Riverton district, it created a “bubble” in the number of physics students enrolled in physics because the number included the upperclassmen still taking physics as well as the freshmen. It also began a period of two years when there was no biology being taught in the school. The general sequence of offerings therefore took two years to implement, as shown in Table 2. While the shift reportedly went smoothly in schools, there was at least one site where it was recognized mid-way through the year that a small group of 12th-graders had not been offered biology, which is a state requirement for graduation. After a rapid reorganization of teacher and student schedules, a double-period biology course was offered to these students in the spring semester.

(Insert Table 2 approximately here)

Goals for shifting to ninth-grade physics. The shift from offering physics as an upper-grade elective to a ninth-grade required course had two specific goals. The main goal was to help improve students' math performance on the two state-mandated standardized tests in mathematics, the first of which was given as an end-of-course exam for algebra and the second as a graduation test for all 11th graders. An algebra-based physics course for ninth-graders, to be taken concurrently with algebra for most students, held the promise of not only increasing the amount of time that students had exposure to mathematics, but also presented an applied setting for the use of the mathematical concepts students were learning.

The second goal in the shift to Physics First was to lay the groundwork for increasing enrollment in Advanced Placement (AP) classes across the district. In 2008, there were only 15 students enrolled in AP science classes in Riverton, all in a single AP chemistry class at a science-themed magnet school. Indeed, the district offered very few AP classes at all. Improving college preparedness had been a district goal, and ramping up the numbers of students taking AP courses—and passing the exam for credit—was seen as one sure way to do this.

Affordances, constraints, and lessons learned. Given that the expressed purpose of shifting the physics to freshman year was to strengthen the mathematics, one of the affordances was that doing so allowed for physics teachers and algebra teachers to collaborate in order to coordinate their efforts. The evidence of this collaboration from the interviews suggests that it was sporadic and individual within the academies, and not yet systematized across the district.

One of the constraints raised by the district administrator was that the limitation of three teacher preparations per year held the district back from being able to offer more AP courses. In fact, the AP Chemistry class is no longer taught, but three sections of AP Physics are now running in the district. The total number of students taking AP courses has remained essentially unchanged since 2008, and from state reporting data, it does not appear that any student in the district has scored a passing grade on an AP science test (3 or higher) from 2009-2013.

One issue that arose during the first and second years of the switch concerned communication with guidance counselors for scheduling. Many of the counselors had difficulty differentiating between students who were following the older Biology-10/Chemistry-11/Physics-12 sequence, and students who were following the newer Physics First sequence, and ultimately, according to one administrator, "The only ones who really knew what was going on were the teachers and the supervisors."

Another limitation of the course reorganization had to do with the teaching of algebra in the physics class. One administrator reported that this was largely an issue of having the pedagogical content knowledge for algebra remediation: "Students who are algebra-ready fare better than students who are weaker. Unless the person teaching has a math background, they can't help the students as much." (Riverton Administrator, 6 Feb 2014).

Both the administrator and teacher interviewed for this research felt that there was a problem-solving focus in the ninth-grade physics class. While the teacher saw this positively, the administrator noted that this came at the expense of conceptual thinking and literacy skills over the three years of the curriculum. "It may be doing something with math scores, but it's not doing anything to help raise language arts scores…students expect to read less in science class because they've been learning from slides for three years" (Riverton Administrator, 6 Feb 2014).

One of the lessons learned from implementing this curriculum was the importance of ensuring that students take physics and algebra concurrently. In the case of students who are not considered algebra-ready by ninth-grade, having alternate course assignments available—such as general science—was necessary. Most of these students currently enroll in physics during their tenth-grade year, but recently in some of the district schools, a 10th grade biology course has emerged as another option. Such sequence deviations are not standard across all of the district schools, leading to some having a stronger fidelity to the Physics First/SIFT curricular model than others. Also, the consequences of losing track of which students had not taken biology during the shift has not been forgotten, further highlighting the need to carefully monitor and advise students on course selections during a course sequence reorganization.

A final lesson learned from the Physics First shift in Riverton concerns the value of implementing this change first in a small number of schools where the chance of success was high. This pilot year of implementation helped to inform the next two years as other schools shifted their programs, and allowed for the certification of enough physics teachers at each school within a reasonable timeframe. While each school or academy was relatively independent in terms of the particulars of the change, the coordination of the Physics First adoption effort led to it being implemented district-wide.

Case #2: Northland

The Northland School District is a relatively small, densely populated suburb located on the outskirts of a metropolitan area. The demographics of the district in state reporting documents show that about 70% of the students identify as White and about 25% as Hispanic. Fewer than 30% of students come from a household where the primary language is other than

English, and less than 20% are identified as economically disadvantaged. The dropout rate at the district's single high school is less than 1%. Despite being in the shadow of a major U.S. city, Northland possesses the close-knit community of a small town.

In the spring of 2010, the superintendent of the district asked the science supervisor—who will be referred to here as Mr. Salviati—his opinion of teaching physics as a ninth-grade subject. Mr. Salviati, a thirty-year veteran physics teacher who had been the district's science supervisor for 20 years, as well as a leader in state and national physics teaching organizations, replied that it could work if done the right way.

Thus began a four-year process to overhaul the high school science curriculum at Northland High School. "We didn't just say we're doing this and change it the next year," Mr. Salviati reported. "It was a two year lead-in before making the change." As a supervisor, Mr. Salviati had continued to teach physics and had planned to continue to do so in the reorganized course sequence. When the math supervisor position opened up the in the summer of 2011, he left the classroom and took on the jobs of both math and science supervisor. For his replacement, he hired a freshly graduated physics teacher from a respected physics teaching program at the state's flagship university who had been prepared using a physics curriculum closely aligned to the physics modeling curriculum (Hestenes, 1997) already in use at the school.

In the fall of 2011, the first course sequence changes were made at the high school. "To ease the pain," Mr. Salviati reported, "the year prior to switching [to freshman physics] I made another change where our sequence was biology-physics-chemistry. So some of the kids took physics before chemistry, so the following year I didn't need as many physics teachers."

Nevertheless, during the transition years it was clear that there would be extra chemistry and physics sections, and fewer biology classes, and Mr. Salviati leveraged the flexibility of his more veteran teachers who had broader certifications that permitted them to teach chemistry and physics during the transition.[6]

(insert Table 3 approximately here)

In the fall of 2012, another physics teacher was hired, but only stayed for one year. A new physics teacher was hired in 2013 from the same flagship university program as the teacher hired two years earlier; as a result, they were in greater alignment for collaboration in planning for freshman physics. During the last two years of the transition, only a single biology class was offered, and that was to ensure that the handful of students (less than a dozen) who had transferred into the school would be able to take the course.

As the supervisor for both the science and mathematics departments, Mr. Salviati was able to create a new schedule that paired physics and algebra in a block of three, 40-minute periods, which offered opportunities to hold a "lab period" for both courses. He felt very strongly that the physics and algebra teachers ought to work cooperatively and the classes should be homogeneous for the 3 period block each day. Mr. Salviati reported, "Having the algebra teacher ask the class to take out their data from physics class to analyze is a very powerful link" (Interview, 16 July 2013). A sample student schedule for this arrangement is shown in Table 4.

(insert Table 4 approximately here)

[6] Science teachers in the state who were certified prior to 1992 received a comprehensive science endorsement that permitted them to teach any high school science subject. From 1993–2004, teachers either received life science, physical science or earth science certification. The state created individual physics and chemistry certifications in 2004, and the requirements for the more comprehensive physical science certification became more stringent.

Goals for shifting to ninth-grade physics. The initial motivation to move physics to the ninth-grade was driven in part by the desire to improve mathematics scores on the state examinations, and a main goal of the shift was to address students' perceptions of a disconnect between high school physics and algebra. An ancillary benefit was that the shifting of biology to the 11th grade year was anticipated to raise scores in the state-mandated End-of-Course Biology exam by virtue of testing students with two more years of schooling.

Affordances, constraints, and lessons learned. Making this shift allowed for a number of other changes to occur at Northland High School that led to a more coherent approach in both math and science. Given that all ninth-graders were enrolled in physics, this presented an opportunity to move away from multiple tracks of ninth-grade algebra and create a coherent math and physics experience for all freshmen. Students who required extra support in mathematics took an extra math class that focused on state test preparation instead of being separately tracked for algebra. The math and physics coherence was further fostered by the teachers' common period once per week on Fridays during the freshman seminar, as well as by a quarterly math/physics project. The common use of data between math and physics also led to a greater sharing of data collection techniques with the math teachers. Another notable effect of this shift was the positive impact on the other science and mathematics courses in the school: upper level science and mathematics course-taking significantly increased since the switch to Physics First and the dissolution of tracked algebra classes.

The constraint of certifications was less of an issue in Northland than it may have been elsewhere, given the small size of the district, the multiple certifications of the Northland staff, and their willingness to accept a temporary physics or chemistry class outside of their regular biology assignments. Yet the ninth-grade physics curriculum placed demands on both physics and algebra teachers alike, and strategic hiring was portrayed as essential by the administration.

A number of the lessons learned from this shift to Physics First concerned the link between the physics and mathematics. Mr. Salviati reported, “I’ve come to the realization that the math has to drive the physics because they’re tested in math, even though deep down in my heart I feel the other way around.” To this end, the coordination between the two courses has continued to grow. For example, the physics teachers have started at the beginning of the year with more qualitative topics, such as optics and electromagnetism, and delayed the study of mechanics for a month to allow time for the algebra teachers to “catch up” with the necessary mathematics. At least one of the ninth-grade math teachers has also attended a summer physics workshop in order to better understand the algebraic demands of the physics classes. It would also seem that having the individual charged with overseeing the shift to Physics First concurrently performing the job of both mathematics and science supervisor helped a great deal.

Case #3: South Hills

The South Hills School District is a relatively small, exurban community that has tripled its student population in the past two decades. It has a single high school and the demographics of the district in state reporting documents show that about 65% of the students identify as White and about 30% as Asian. Fewer than 7% of students come from a household where the primary language is other than English, and less than 3% are identified as economically disadvantaged. Though somewhat rural in character, the South Hills community is in close proximity to a prestigious research university, and has numerous scientific, technological, and financial firms located nearby. An internal survey conducted by the South Hills High School science department found that 75% of the district's ninth-graders have one or both parents working in a science, technology, engineering, or mathematics (STEM) industry.

The story of the shift to Physics First in South Hills begins in the 1990s, when changes in the state science standards influenced the district to alter their science course sequence to address the announced state high school graduation exam that would cover topics from all sciences. The most immediate consequence was that three years of academic science became mandatory for all students. Yet, the district recognized that if the exams were given in the fall of the 11th grade year as announced, at least one science course would be shortchanged. As a result, a series of semester-long courses were offered: Biology 1, Chemistry 1, Physics 1, Biology 2, Chemistry 2, and Physics 2. This shift permitted the district to ensure that all students had each of the courses prior to the graduation exam. When the comprehensive graduation exam was postponed indefinitely by the state, the South Hills district was left with a course sequence that made little sense to either teachers or parents.

(insert Table 5 approximately here)

With the support of the superintendent and school board, the science supervisor at the time made the decision to require all students in the district to take physics in ninth-grade. "We weren't trying to do 11th grade physics with freshmen. We *were* trying to do hands-on inquiry based science" (former South Hills science supervisor, 20 March 2014). This change required ensuring that those enrolled in the half-year science courses were able to complete their sequence, while the students beginning the Physics First sequence followed their own series of courses. This led to a complicated schedule over the next few years, as shown in Table 5.

The initial years of Physics First in the district were not marked by the curricular and pedagogical coherence that was to come later in the South Hills High School science department. Despite the reorganization of the physics curriculum for ninth-graders, many of the teachers felt that the curriculum remained oriented towards to the 11th grade level.

One of the new hires that year, called Mr. Gregg here, had recently made the switch from industry to teaching through the state's alternate route teacher certification program. In the summer after his first year of teaching, Mr. Gregg attended a national conference (Roeder, 2003) dedicated to discussing the idea of reordering the biology-chemistry-physics sequence in high school science. He later participated in a residential workshop at Arizona State University to learn the physics modeling instruction curriculum.

Those interviewed for this study at South Hills point to the practices spread by Mr. Gregg in the few years following this workshop as a precipitating factor in the pedagogical changes that would eventually transform the department. He began using the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) in his own classes to assess the effect of his physics teaching, and asked other teachers to use it as well. The FCI results had the same impact as it had elsewhere, in that students often did poorly on questions that appeared very easy to teachers, and showed that physics instruction had done little to dislodge misconceptions.

By 2005, other modeling practices had begun to spread through the department, including the use of whiteboarding. Mr. Gregg noted that this happened when other teachers observed his use of the whiteboard, and felt that their adoption of whiteboarding and other modeling strategies was initially unconnected to the philosophical orientation of model development and refinement, but it did lead to an increasing alignment of practice.

The district science supervisor attended a modeling workshop with a new hire in 2007, and from that point forward the ninth-grade physics approach became much more coherent within the department. In 2009, the district ran a modeling workshop using its own teachers as instructors to train the remaining teachers—as well as teachers from around the state—in the modeling method. Currently, all ninth-grade students take physics in a modeling environment.

Goals for shifting to ninth-grade physics. In the spring of 2002, it was clear that the semester sequence of science courses needed to change, and so the shift to Physics First was driven by the need to reexamine the course sequence and select a different approach. Therefore, at least in a pragmatic sense, this was as much a shift *away* from a particular approach as it was a shift towards another. While the district could have returned to its earlier course sequences, with the three-year requirement added in, the science supervisor at the time researched a variety of possible options and chose the Physics First approach.

There were three specific goals driving this decision. The former supervisor described the first as "a local argument" grounded in the goals of 21st century biology. She described the state as "a hotbed for biotech and pharmaceuticals," and further noted, " I do not want to teach yesterday's biology to freshmen. I do not want to teach nomenclature to 13-year-olds and 14-year-olds. I want to teach biochemistry to juniors." One teacher commented on the label Physics First, stating that it should be called "Capstone Biology" instead to put the emphasis on where students are going. Also discussed at the time was the rationale for a ninth-grade physics, suggesting that “physics is macroscopic and students in ninth-grade are still concrete operational learners, and it matches their cognitive abilities much better than a chemistry or biochemistry approach” (former South Hills science supervisor, 20 March 2014). The second goal was for the eighth- and ninth-graders in math classes to see a purpose for algebra, and it was thought that a ninth-grade physics class would allow another venue for students to use and practice the mathematics they were learning. A final goal concerned ensuring gender equity in upper-level science courses; historically, a gendered pattern of physics course-taking existed in the district because girls enrolled in science elective courses instead of physics.

Affordances, constraints, and lessons learned. The goal of ensuring that all students have access to physics has certainly been achieved in South Hills. Even students who do not pass the state eighth-grade mathematics test take physics, and the district is currently looking at ways to better integrate the math and physics instruction. This goal of access to science courses extended to upper-level courses as well, and the district now allows any student to sign up for an honors or AP course without prerequisites.[7] The science supervisor reported that gender balance now exists across all science courses.

It is possible that the modeling approach may have taken root in South Hills even without a Physics First curricular sequence, yet the push for a more developmentally appropriate physics for ninth-graders led the teachers to explore changes in their

[7] Enrollments in Advanced Placement science courses have dramatically increased since prerequisites were removed. AP Physics B was taught to 12 students in 2005, and over 120 in 2013.

pedagogy. The modeling approach led to instructional coherence across classrooms, allowing teachers to share their resources and practices in pursuit of common goals.

One of the constraints raised by interviewees concerned the dependence of the current approach on trained personnel, and its ultimate sustainability over time as the career arcs of faculty move them out into new challenges. The science supervisor noted the difficulty of finding people with the right level of expertise and getting them trained, which is, as he put it, “above and beyond just finding a physics teacher who likes children and wants to teach ninth-graders,” (interview, 15 March 2013). Yet, as the former science supervisor pointed out, making the shift to Physics First was entirely dependent on personnel and certifications.

Another constraint—at least for the physics teachers—was the relative inflexibility of the algebra curriculum, which has stymied efforts to articulate content between that course and physics. One of the departmental efforts this year has been to improve this coordination, but progress has been slow. In terms of the physics curriculum itself, the majority of the year is focused on mechanics, and while there have been various attempts to delay the necessity of algebra in the first month of the school year by focusing on optics or electromagnetism, a suitable solution to this issue has yet to be found.

Discussion

Conceptualization of “Physics First”

Though all districts in the study offered physics in the ninth-grade, the manner in which each district conceptualized Physics First was not completely shared. In the three districts, ninth-grade physics was mandatory for all students, though the degree to which each district supported students with disabilities and English language learners in these classes differed. In all of the cases, there was also a revision of the actual course content of physics to better meet the needs of ninth-graders, as well as to support the required and advanced science courses that students would later take in high school.

In the two single-high-school suburban districts, the ninth-grade physics program was conceptualized as a math/science integration program, with the ninth-grade algebra teachers closely involved in supporting the mathematics needed for each physics unit, even though this proved difficult in practice. In the larger urban district, such integration was desired, but not supported structurally within the school. Rather, the freshman physics program there had a very explicit focus on supporting the larger district goal of increasing the numbers of students taking Advanced Placement courses, a common metric used to evaluate school quality.

Every person interviewed for this study mentioned that improving students' mathematics skills was a strong rationale for teaching physics in the ninth-grade. They all felt that the data from their district pointed to improved math scores on the state mathematics tests. While the evaluation of such claims remains an area for future research—particularly the untangling of causality chains for academic achievement—clearly the belief that taking ninth-grade physics aided students in mathematics was an aspect of its sustained support in districts.

To summarize, Physics First programs in all three districts were conceptualized as distinctly different from traditional upper-level physics courses because of the way that they supported the algebraic understandings and skills students gained in their mathematics courses. They were also conceptualized as foundational to further studies in chemistry and biology, and seen as a crucial step toward increasing the enrollment in other advanced science courses such as Advanced Placement Physics. In these districts, Physics First was also seen as an equity measure, particularly in terms of attempting to foster the eventual participation of girls in upper-level science courses.

Contextual Factors influencing adoption of Physics First

A common feature across the three programs was a stated commitment to student-centered and constructivist pedagogy, yet each of the programs struggled with enacting this in a ninth-grade physics program in ways unique to their contexts. While South Hills and Northland employed a pedagogy rooted in the modeling approach to physics teaching—working from data collected by students to build explanatory models and identify relationships—the SIFT curriculum in Riverton used a constructivist approach solely in the solving of set problems. Round tables and student talk were key features of SIFT classrooms, but there were far fewer opportunities to collect data and design experiments in the lessons. Another point raised by interviewees in each district was the need for outreach and communication with the community to make the case for ninth-grade physics, because of the public perception that physics was an elite and difficult course. Multiple individuals at South Hills—which has had Physics First now for over a decade—stated that this task of educating the community about the nature of ninth-grade physics has been an ongoing effort and will continue into the foreseeable future.

Issues of leadership, certification, and staffing strongly impacted the adoption, implementation and sustainability of the ninth-grade physics program in each of the districts. Large urban districts like Riverton often struggle each year to staff classes with enough certified physics teachers (Ingersoll & Perda, 2010), and the shift to Physics First appears contingent on being able to keep these positions filled—an uncertain proposition given the historically high turnover of teachers in the district. Indeed, in Riverton the shortage of certified physics teachers was the driving force behind the initial adoption of Physics First, and it remains to be seen if the certification of additional physics teachers is sufficient to sustain the curricular reform.

In the smaller suburban districts, there was a very focused effort on ensuring that high-quality personnel were available to teach in the program. Of course, given the size of these programs, fewer personnel were needed. In the case of Northland, two new physics teachers were recruited from the same highly regarded university physics teacher preparation program where the physics curriculum used by the district had also been developed. This supported the district supervisor's goal of fostering philosophical coherence across the department. In South Hills, there was a long term effort to develop such coherence in the program through the professional development of existing staff, who were all eventually trained in the Modeling Physics program developed at Arizona State University (Hestenes, 1997).

One notable finding across all districts was the tremendous logistical planning needed to shift from a biology-chemistry-physics sequence to a program that offers physics at the ninth-grade level and biology at the 11th grade level. Such planning included careful attention to managing precipitous drops in biology course enrollments during this transition. In the case of Northland, veteran teachers with the older (and no-longer available) comprehensive state certifications in biology, chemistry, and physics, made this scheduling possible. The small size of the school and the modular scheduling already in place was also a factor. In Riverton, this transition was much more difficult, and involved teachers seeking coursework to gain additional certifications.

Conclusion & Implications

To answer the first research question, in each district the conceptualization of the Physics First approach included setting a foundation for future high school science coursework and strengthening students' mathematics abilities through application in physics. Some aspects of what constitutes a Physics First approach in ninth-grade is not yet settled, and indeed one of the findings of this study is that there is not one singular ideology, pedagogy or curriculum that can carry that label. As this study shows, there are significant differences in physics pedagogy across school districts engaging in a Physics First approach. Other issues that differ across the cases concern the district and school mathematical prerequisites for taking physics, and when and how mathematical remediation ought to take place. There is also the issue of whether physics ought to be a course taken by all freshmen, or whether it better serves as an elective or honors course.

While this research did not examine the effectiveness of the Physics First approaches, it did uncover a number of metrics in use by the participating districts that could be useful in evaluating the ultimate impact of such a shift. These indicators include:

- End of course physics tests, mathematics exams, state-mandated math tests
- Advanced-course taking beyond required courses, including Advanced Placement courses and particularly sophomores in AP Physics
- The Force Concept Inventory (pre- and post-tests) (Hestenes et al., 1992)
- Demographic profile (race, SES, gender) of advanced science courses as compared to ninth-grade population.
- Retention, new certification, and turnover of personnel certified to teach physics.

To address the second research question, in nearly every case, the task of coordinating algebra courses to foster coherence with ninth-grade physics was much more difficult than anticipated. Missing from a number of programs was a clear articulation of a specific plan that included mathematics faculty. In the case of Northland, with one individual serving both as mathematics and science supervisor, this coordination required sustained work with individual math and physics teachers. In Riverton, the coordination was simply periodic communication between colleagues.

Mathematics is not the only subject to require articulation with physics, however. The framing of such changes as Physics First or even “Capstone Biology” points to the fact that the subject of chemistry suffers from what one of the South Hills physics teachers referred to as “middle child syndrome,” in that unless explicit attention is paid to how these reforms impact chemistry pedagogy or curriculum, it tends to be ignored.

While the actual reorganization of the course sequence to accommodate a change to a Physics First approach seemed relatively straightforward in all of the cases, most took a great deal of planning over a period of years to implement. As a result of this planning, in nearly every district the biology course offerings were substantially reduced for up to two years, and the biology teachers either had to teach a different course within their certification area (e.g. chemistry, environmental science), enroll in a physics certification program to be permitted to teach physics, or leave the school.

As the first independent studies begin to emerge on the effectiveness of the Physics First approach to high school science (e.g. Glasser, 2012), it remains important to ensure that the details of implementing such reforms remain a part of the conversation. For the moment, there is shared agreement about Physics First as the realignment of the high school curricular sequence, but there is less consensus about other details such as how such programs are aligned with mathematics or whether they ameliorate or magnify inequities in schooling. The emergence of the revised Advanced Placement Physics 1 & 2 exams to replace the previous Physics-B exam, may lead to further interest in AP Physics 1 as a ninth-grade physics course. Future research to investigate the effectiveness of current Physics First efforts, as well as the broader impact within schools and districts is certainly warranted.

It is clear that Physics First does not represent one particular philosophy, curriculum or set of pedagogies. It also appears necessary to attend to the role of accountability pressures—such as state test scores and Advanced Placement test-taking rates—to ensure that the broad aims of developing scientific understandings are not co-opted in the service of narrower goals.

References

Bessin, B. (2007). Why Physics First? Physics Teacher, pp. 134-134.

Bybee, R. W., & Gardner, A. L. (2006). High School Biology & the Physics First Movement. American Biology Teacher, pp. 134-138.

Cuban, L. (2013). Inside the Black Box of Classroom Practice: Change Without Reform in American Education: Harvard Education Publishing Group.

DeBoer, G. E. (1991). A history of ideas in science education: Implications for practice. New York: Teachers College Press.

Glasser, H. M. (2012). The Numbers Speak: Physics First Supports Math Performance. Physics Teacher, 50(1), 53-55.

Haber-Schaim, U. (1984). High school physics should be taught before chemistry and biology. The Physics Teacher, 22, 330 -332. The Physics Teacher, 22, 330 -332.

Halverson, R. R. (2004). Accessing, Documenting, and Communicating Practical Wisdom: The Phronesis of School Leadership Practice. American Journal of Education, 111(1ov).

Hestenes, D. (1997). Modeling methodology for physics teachers. In Redish, E. & Rigden, J. (Eds.), The changing role of the physics department in modern universities. (Vol. 2, pp. 935-957.): American Institute of Physics.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. The Physics Teacher, 30, p. 141−158.

Ingersoll, R. M., & Perda, D. (2010). Is the Supply of Mathematics and Science Teachers Sufficient? American Educational Research Journal, 47(3), 563-594.

Lederman, L. M. (1998). ARISE: American Renaissance in Science Education. Fermilab. Batavia, IL.

National Research Council. (2012). A framework for K-12 science education: practices, crosscutting concepts, and core ideas. Washington, D.C.: The National Academies Press.

Roeder, J. L. (2003). 'Physics First': First Conference Held at Cornell. Cornell University Laboratory for Elementary-Particle Physics, New York.

Rudolph, J. L. (2002). Scientists in the classroom: The cold war reconstruction of American science education (1st ed.). New York: Palgrave Macmillan.

Sheppard, K., & Robbins, D. M. (2009). The "First Physics First" Movement, 1880-1920. Physics Teacher, 47(1), 46-50.

Stake, R. E. (2000). Case studies. In Denzin, N. & Lincoln, Y. (Eds.), Handbook of qualitative research (Vol. Second edition, pp. 435-454). Thousand Oaks, CA: Sage.

Stake, R. E. (2006). Multiple case study analysis. New York: The Guilford Press.

United States National Commission on Excellence in Education. (1983). A nation at risk: The imperative for educational reform. A report to the Nation and the Secretary of Education, United States Department of Education. Washington, D.C.

White, S., & Tesfaye, C. L. (2010). High school physics courses & enrollments: Results from the 2008-09 nationwide survey of high school physics teachers. American Institute of Physics.

Table 1

Characteristics of Districts Participating in This Study

District Name	District Description	District student population[a]	Initial Year of Physics First
Riverton	Urban/low-SES	>20,000	2008
Northland	Suburban/mid-SES	2000	2011
South Hills	Suburban/high-SES	5000	2002

[1] The school population data is drawn from state reports, and is rounded to preserve the confidentiality of the participants in this study who might otherwise be identifiable.

Table 2

Course sequence during science curriculum reorganization in Riverton

Grade	Year 0	Year 1	Year 2	Year 3
9	Geophysical Systems (General Science)	SIFT physics	SIFT Physics	SIFT Physics
10	Biology 10	Biology 10	SIFT Chemistry	SIFT Chemistry
11	Chemistry 11 and/or electives	Chemistry 11	Chemistry 11	SIFT Biology
12	Physics 12, AP Chemistry, and/or electives	Physics 12 AP Chemistry, and/or electives	Physics 12 AP Chemistry, and/or electives	AP Physics B, AP Chemistry, and/or electives

Table 3

Course sequence during science curriculum reorganization at Northland High School

Grade	Year 0	Year 1	Year 2	Year 3	Year 4
9	Biology or Physical Science	Biology	Physics	Physics	Physics
10	Chemistry or Biology	Physics	Chemistry	Chemistry	Chemistry
11	Physics or Chemistry	Chemistry	Physics or Chemistry	Physics	Biology

Note. During years 0 & 1 at Northland, the electives and advanced offerings included Physics II, Anatomy & Physiology, Environmental Science, AP Biology, and Technology Lab. After year 2, the Technology lab was replaced with Exploring Computer Science, Exploring the Animal Kingdom, and Exploring Space Science as electives.

Table 4

Sample Student Schedule Showing the Physics/Math Block at Northland High School

Period	Monday	Tuesday	Wednesday	Thursday	Friday
1	Physics	Physics	Physics	Physics	Physics
2	Physics Lab	Algebra Lab	Physics Lab	Algebra Lab	Test prep/Seminar
3	Algebra	Algebra	Algebra	Algebra	Algebra

Table 5

Four-year sequence of changes at South Hills High School

Grade	Year 0	Year 1	Year 2	Year 3
9	Bio 1/ Chem 1	Physics 9	Physics 9	Physics 9
10	Physics 1/ Bio 2	Physics 1/ Bio 2	Chemistry 10	Chemistry 10
11	Chem 2/ Phys 2	Chem 2/ Phys 2	Chem 2/ Phys 2	Biology 11