ABSTRACT

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ABSTRACT

Hundreds of high schools around the United States have inverted the traditional core sequence of high school science courses, putting physics first, followed by chemistry, and then biology. A quarter-century of theory, opinion, and anecdote are available, but the literature lacks empirical evidence of the effects of the program. The current study was designed to investigate the effects of the program on science achievement gain, growth in attitude toward science, and growth in understanding of the nature of scientific knowledge.

One hundred eighty-five honor students participated in this quasi-experiment, self-selecting into either the traditional or inverted sequence. Students took the *Explore* test as freshmen, and the *Plan* test as sophomores. Gain scores were calculated for the composite scores and for the science and mathematics subscale scores. A two-factor analysis of variance (ANOVA) on course sequence and cohort showed significantly greater composite score gains by students taking the inverted sequence.

Participants were administered surveys measuring attitude toward science and understanding of the nature of scientific knowledge twice per year. A multilevel growth model, compared across program groups, did not show any significant effect of the inverted sequence on either attitude or understanding of the

nature of scientific knowledge. The sole significant parameter showed a decline in student attitude independent of course sequence toward science over the first two years of high school.

The results of this study support the theory that moving physics to the front of the science sequence can improve achievement. The importance of the composite gain score on tests vertically aligned with the high-stakes ACT is discussed, and several ideas for extensions of the current study are offered.

NORTHERN ILLINOIS UNIVERSITY

A QUANTITATIVE STUDY OF A PHYSICS-FIRST PILOT PROGRAM

THESIS SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

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ASSESSMENT

BY

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Certification: In accordance with departmental and Graduate School policies, this thesis is accepted in partial fulfillment of degree requirements.

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DEDICATION

For Eileen, Evan, and Cora

Thank you for your encouragement, patience, and love

Also, for Tom Jordan

Your steadfastness and dedication, as well as your insistence on always asking

"Why?" motivates me to always work harder, in all aspects of my life

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CHAPTER 1

INTRODUCTION TO THE STUDY

The physics-first "movement" is a loose collection of physics teachers and others interested in inverting the sequence of core high school science courses from the traditional biology–chemistry–physics (B–C–P) to physics–chemistry–biology (P–C–B). This movement began in the early 1970s, and counts as its supporters such distinguished physicists as Uri Haber-Schaim and Nobel Laureate Leon Lederman. With each new distinguished advocate, but perhaps especially with Lederman, the movement has continued to draw adherents and grow in prestige. Arguments in support of the inversion are based on observations about the respective natures of biology, chemistry, and physics, and from there on sound logic. Numerous high school science teachers at schools with P–C–B curricula report success for their students and school as a result of the inversion (e.g., Hewitt, 1990; Hickman, 1990; Myers Jr., 1987; Pasero 2001). In short, a review of the literature will uncover abundant advocacy in the form of theory, opinion, and anecdote. What is largely missing, however, are quantitative data on outcomes of the inverted sequence (Pasero, 2001). The purpose of the present study will be to examine those outcomes in depth at one particular school to see what can be learned.

History of the Traditional Sequence

Most Americans who took three years of high school science probably have somewhat similar memories: biology first, then chemistry, and finally physics. The common understanding of the sequence is a logical one. Biology as taught in most American high schools is largely a descriptive science, with very little math involved. Chemistry also includes a descriptive element, but adds quantitative aspects and some algebra as well. Physics is widely seen as the most difficult because it incorporates not only algebra, but also geometry and trigonometry (and in some high schools, calculus).

This sequence was put into place largely due to the work of a prestigious committee convened near the end of the nineteenth century by the National Education Association (NEA). This committee, chaired by Harvard president Charles Eliot, was created to develop a common basis of coursework for American high schools, so that universities accepting their students would have a more consistent idea of how those students had been prepared (DeBoer, 1991). The report of the physical science subcommittee to the full committee recommended that chemistry be taught before physics (biology, at that time split into botany, zoology, and physiology, was given to a separate subcommittee on natural history), despite stating that this order was "plainly not the logical one" (NEA, 1893, p. 119). The justification for making the recommendation that was "plainly" counter-indicated by logic should sound familiar: ". . . pupils should have as much mathematical knowledge as possible to enable them to deal satisfactorily with Physics [*sic*]." (NEA, 1893, p. 119). Despite the rejection of

this recommendation by the full committee, which instead suggested physics before chemistry in all four of its proposed courses of study, high schools chose to follow the advice of the physical science subcommittee (Sheppard & Robbins, 2002). When biology coalesced from three courses to one, it was typically placed first, thus today almost all high schools in the United States have a biology–chemistry–physics (B–C–P) core science sequence.

History of the Physics-First Movement

There is currently an informal, loosely organized movement to invert the now traditional B–C–P sequence, making physics the first science that high school students encounter, and biology the last. The seeds for this movement were planted with a flurry of articles in *The Physics Teacher* in the early 1970s (Hamilton, 1970; Palombi, 1971; Swartz, 1971). At that time, a handful of schools, often led by their physics teachers, began to invert their science sequences. The movement got a boost in 1984, this time from esteemed physicist and educator Uri Haber-Schaim, who wrote a *Physics Teacher* article titled "High school physics should be taught before chemistry and biology" (Haber-Schaim, 1984). In it, he laid out three tables of topics covered by high school science textbooks of the time. Two lengthy tables were titled "Chemistry Prerequisites in Biology Texts" and "Physics Prerequisites in Chemistry Texts." The third, much shorter, table was titled "Chemistry Prerequisites in Physics Texts," and he tellingly included no table listing biology prerequisites for either physics or chemistry. Based on this, he drew the conclusion "…that given the content of today's

senior high school courses, the sequence should be physics–chemistry–biology." (Haber-Schaim, 1984, p. 331). This article and others that followed inspired a new set of teachers and schools to invert their sequences, and more articles from such teachers resulted (e.g., Hickman, 1990; Myers, 1987). Unfortunately, these were also based on theory and anecdote, not on research.

The most recent champion of the movement has been Leon Lederman. Lederman's work in this area began when he convened Project ARISE (American Renaissance In Science Education) in 1995. Since that time, he has written and spoken in a great number of forums advocating for the inversion (e.g., Bardeen & Lederman 1998; Lederman, 1995; Lederman, 2001a, 2001b). Lederman's arguments and charisma have again increased interest and participation in the movement.

Along with his list of prerequisites, Uri Haber-Schaim in his landmark 1984 article laid out what is probably still the most commonly given explanation for inversion to a P–C–B curriculum. His explanation has to do with the changes that took place in the sciences themselves over the course of the twentieth century:

> . . . the sequence biology–chemistry–physics . . . . was introduced in the early years of the 20th century. At that time biology was largely descriptive botany and zoology. Chemistry was also descriptive and largely qualitative, with the exception of the laws of constant and multiple proportions. Physics, which was considered more demanding mathematically, was placed at the end of the sequence. In those days the biology required no chemistry and the chemistry required no physics. Today . . . . tenth-grade biology has substantial prerequisites in chemistry, and chemistry has substantial prerequisites in physics. (p. 330)

Myers (1987) echoes these arguments in further detail, describing the advances in technology that allowed for a chemistry-based understanding of biological

processes and a physics-based understanding of chemical processes. He also puts forth the ideas of mathematical reinforcement, which he describes as a use of the physics-first course to provide students with applications for their recently gained algebra skills. Under the traditional sequence, Myers argues, students who take algebra in 9th grade will see it as little more than an abstraction until their 12th grade physics class. Moving physics to the front of the science sequence (he suggests 10th grade) will allow students rapid reinforcement of their algebra through regular use. Today, many schools offering physics first offer it concurrently with algebra, an extension of Myers's idea.

Statement of the Problem

The idea of inverting the traditional science sequence to put physics first, chemistry second, and biology third has grown sufficiently that it deserves serious study. There are a variety of theoretical reasons for making the change, most notably that it reflects the changes in the nature of the sciences and in their relationships to one another that have taken place over the century that has passed since the traditional sequence was established. Although the idea of inverting the traditional science sequence has significant theoretical and anecdotal support, empirical support is not available in the current literature.

There are significant costs associated with making the change to the inverted sequence. Most obvious are the costs of the textbooks that will be needed for the new courses. Also, during the change, there will be two years in which a school will need

more than its usual number of physics courses, and fewer biology courses than normal. (In the case of a full-school change in one year, no biology courses at all.) This will require schools to invest in retraining some teachers to teach physics. Depending on conditions of implementation, this may cause teacher morale to decline.

All of these costs, as well as parent and community expectations, should lead a school system's stakeholders—teachers, department chairs, administrators, school boards, parents, and concerned citizens—to seek evidence that the change is worth making before committing fully to it. The most important consideration in the eyes of most of these stakeholders will be student achievement, as measured by a high-stakes exam such as the ACT, student scores on which influence college admissions decisions and determination of Illinois schools' yearly progress under the No Child Left Behind Law.

For this reason, student achievement was selected as the primary area of interest in this study. I elected to study science and math achievement because the science program is the one being modified, and because of the close relationship between mathematics and science. Because the science sections of the ACT and its related exams focus on science reasoning rather than on content, understanding of the nature of scientific knowledge was selected as a supporting variable. Attitude toward science was also selected for study because it has been demonstrated as a predictor of science achievement, as will be demonstrated in Chapter 2.

Purpose

The present study uses longitudinal data analysis based on achievement and attitude measures, as well as a measure of student understanding of the nature of scientific knowledge, to compare students in the traditional core sequence of courses with students in the physics-first sequence of courses on science achievement, mathematics achievement, overall achievement, attitude toward science in school, and understanding of the nature of scientific knowledge.

Research Questions

This study addresses the following research questions:

1. Are there statistically significant differences in achievement gain in science, mathematics, or overall, over the first two years of high school, between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

2. Are there statistically significant differences in the growth trajectories in attitude toward science through the first two years of high school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

3. Are there statistically significant differences in the growth trajectories in understanding the nature of scientific knowledge through the first two years of high

school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

Significance of the Study

Helping students achieve scientific literacy, an ability to understand and process scientific information on some level (but not necessarily at the level of an expert), is a concern for all science educators. An understanding of scientific ways of thinking, including the necessity of data, the use of logic, and the desirability of replicability, are important not only for students who plan to become scientists, but also for students as future citizens, who will need to live and help make societal decisions in a world in which science is increasingly pervasive (Sousa, 1996). A group of physics educators has become concerned about spreading scientific literacy generally, and physics literacy specifically, among high school students. The most common phrasing of this concern is "physics for all" (Hake, 2002).

Some of these educators have created a link from physics-first to physics for all, or to scientific literacy more generally, as they see compatible aims for the two. Myers (1987) anticipated this movement, noting the increased enrollment in physics as a result of the inverted sequence and referring to it as "Population Awareness" (pp. 79–80). Sousa (1996) believes that teaching a physics course to ninth graders will detach it from its historical association with higher mathematics, which many students find intimidating. He claims that this will make "this science much more concrete, understandable, and even enjoyable, especially to students not oriented

toward science," and further, that "connections among sciences," improved by the inverted sequence, will "lead to a deeper understanding, establish relevancy, and result in a greater retention of learning." Finally, Hake (2002) does not believe that the physics-first movement and the quest for more widespread scientific literacy are necessarily linked, but thinks that they share common obstacles, and that physics-first is desirable to the extent that it helps to clear those obstacles to widespread science literacy.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

Available Literature

There exists very little literature specifically relevant to the effects of a physics-first curriculum on science achievement or student understanding of the nature of scientific knowledge. However, there is appreciable research regarding science education focuses on attitude, either as a predictor variable (e.g., of future coursework) or as an outcome variable (e.g., of a particular treatment). Students' understanding of the nature of scientific knowledge has received considerably less treatment.

Here I will examine the theoretical justification behind the physics-first sequence of courses, then discuss the literature regarding student attitude toward science, both as a predictor and as an outcome variable. Then, literature linking attitude with understanding of the nature of science and with achievement will be reviewed, and finally, literature on achievement and on school-level changes will be summarized.

Physics-First Theoretical Justification

Uri Haber-Schaim (1984) was the first to publish an explicit theoretical justification for the physics-first sequence. He pointed out the developments in biology from a largely descriptive science to a quantitative science that requires an understanding of the behavior of atoms and molecules. He also described the evolution of chemistry from a primarily qualitative science to a science that requires more mathematics and an understanding of physics; namely, the physical interactions of atoms, molecules, and their component parts (which had not been discovered when the biology-first sequence was recommended).

Haber-Schaim (1984) compiled three tables of "prerequisites" culled from analyses of commonly used high school biology, chemistry, and physics textbooks. He defined a prerequisite as a "…topic used extensively in [a] course without being developed in it" (p. 330). Each table identified topics from one science that were assumed knowledge in textbooks for a different science. The shortest table of the three was that of chemistry prerequisites in physics texts, listing only chemical bonding and some specific examples of chemical reactions. By contrast, the list of physics prerequisites in chemistry texts was the longest, listing 59 topics as diverse as emission spectra, partial pressures, and nuclear fission. By comparing these two tables, he deduced that physics should come before chemistry. From a similar 48-item table of chemistry prerequisites in biology texts, such as energy, chemical bonds, and hydrolysis, and his inability to find items for a reverse table, he likewise came to the

conclusion that chemistry should precede biology, thus setting up the physics-first sequence.

Bardeen et al. (1998) provide an illustrative example in the form of a sentence, superficially about a biological process, but heavily reliant on physical and chemical underpinnings: "The transmission of sodium and potassium positive ions through cell membranes is crucial to the functioning of nerve impulses." They continue:

> In this one sentence are essential physics and chemical concepts applied to a vital element of biology. If students do not know physics and chemistry, they are forced to memorize a description of nerve impulses. Without physics and chemistry as prerequisites, it's the best that can be done. (p. 6)

Bardeen and Lederman (1998), in proposing a three-year integrated sequence that focuses on physics in the first year, chemistry in the second, and biology in the third, enumerate further connections among the sciences that support the inverted sequence. They propose that a second-year chemistry science course would be able to take advantage of student understanding of atomic structure and characteristics of atoms, which would be developed in the physics-focused first-year course. Further, student understanding of polymerization reactions developed in the second-year course would allow easier entrée to discussions of how the structures of DNA and proteins are formed, and how those structures affect their functions.

Some authors have extended these arguments by including a social dimension. Myers (1987) and Hickman (1990) assert that physics, because of its traditional place at the end of the science sequence, has been widely perceived as the most difficult of the sciences. As a result of this, many high school students who have had the choice

have opted not to take it. Myers and Bardeen et al. (1998) argue that the pervasion of physics into everyday life renders this a gaping hole not only in students' science education, but also in their general education. All point out that moving physics to the front of the science sequence would remedy this, even in high schools that still have a science requirement of only one or two years.

Attitude Toward Science

Attitude as a Predictor

Attitude as a Predictor of Course Enrollment

Student attitudes toward science have received considerable attention in the literature. In the literature, attitude toward science is frequently treated as a predictor variable, highlighting its importance in a variety of areas. Lyons (2005) considered attitude toward science among many other student and school characteristics in examining falling enrollments in secondary physics and chemistry courses. He began by administering one survey to 196 10th grade "A" or "B" science students and another to their 24 teachers. The student survey collected demographic data and data on previous and current courses taken by the students. It also asked students to rate their own science ability, and for information on whose advice the students had solicited in making their decisions about college coursework. The teacher surveys asked about changes in enrollment in science courses, and asked the teachers' opinions

for the cause(s) of declining popularity in upper-level science courses. The surveys were followed up with interviews of 37 of the surveyed students. Student selection for interviews was stratified by the students' plans (if any) for their 11th and 12th grade science courses. The interviews further explored the influence on students' decision-making regarding upper-level science courses.

Lyons found many illuminating effects on student's attitude toward science, beyond his initial goal of simply using attitude to explain falling enrollment. Students' attitudes toward the relative difficulties of the sciences were shaped by their experiences and "from comments by teachers, senior students, peers, and parents" (Lyons, 2005, p. 296). Students enrolling in biology did so because they were told it was the easiest, and students planning to enroll in chemistry and physics were often concerned more with positioning themselves well for their university and later career choices than with any particular interest in the physical sciences. Lyons also found that attitudes toward science and formal education within students' families were an important source of motivation (or its lack) to enroll in further science, but family attitudes are beyond the scope of the present study.

Trumper (2006) also looked at the effects of attitude on course enrollment but took an approach more specifically geared toward physics. He used the ROSE survey, which includes 250 four-point Likert-type items assessing attitudes toward science generally, opinions about science classes, and extracurricular physics experiences, to predict interest in later physics coursework of 635 Israeli junior high students. Trumper formed several latent constructs from the 250 items, and examined both overall interests and attitudes, and compared boys and girls on the same. He found a

precisely neutral mean attitude toward physics (*M* = 2.50 on a scale of 1–4), with a comparatively better attitude toward science and technology generally (*M* = 2.65), and less positive attitudes toward school science (*M* = 2.19) and out-of-school physics experience (*M* = 2.16). For all four variables, boys showed significantly better attitudes or more interest than girls. As might be expected, interest in physics was significantly predicted by the other three variables, most strongly by opinions about science classes. This would seem to indicate that, at any level, students' formative science experiences are crucial not simply intrinsically, but also as laying the groundwork for any future science or physics success (or even attempts).

Attitude as a Predictor of Achievement

Singh, Granville, and Dika (2002) and House (2004) both considered the effects of attitude on achievement (math and science in the case of Singh et al., science only for House). Singh et al. developed a structural equation model using data for 3,227 students from the National Center for Education Statistics NELS:88 study. The latent predictor variables they studied were academic motivation, academic preparation (named as a second motivation construct), attitude (toward math or science), and time spent on academics. They used these to predict the latent outcome variable of achievement (in math or science, per the selected attitude construct). Each latent variable was composed of two or three variables measured directly by the NELS:88 study. Their final model for science indicated that the only construct directly affecting science achievement was time spent on academics, but that it was

itself affected by the three other latent constructs, and more by attitude than by either motivation construct. Interestingly, the mathematics model differed from the science model in that three of the four constructs directly influenced mathematics achievement (motivation, attitude, and time spent on academics), but that attitude's total effect on achievement was not as important as those of motivation or time spent on academics.

House (2004) used data on 16,867 13-year-old Thai students from the Third International Mathematics and Science Study (TIMSS) from 1995 and 1999 to examine relationships between beliefs students hold about themselves and their achievement in science. He utilized survey items relating to students' attitudes and beliefs about science, as well as the TIMMS test itself, which served as a measure of science achievement. He found that when regressing achievement on (1) attitude and (2) belief variables, enjoyment of science was consistently correlated positively with achievement (r =.032, p < .05), as was a belief that memorization of the textbook or notes was necessary to do well (r =.045, p < .05). The belief in a need for memorization held up as a significant predictor for both boys and girls when the surveys were disaggregated by sex, but enjoyment of science was significantly correlated with achievement only for boys. Negative correlations with achievement across all students existed for the belief that, to do well in science, you need good luck (r = –.084), and that science is boring (r = –.045). Both of these beliefs were also correlated negatively with achievement for boys, but for girls, the negative correlation with boredom did not hold. Instead, there was a negative correlation between achievement and the belief in a need for natural talent to do well at science (r = –.055).

The results of these studies demonstrate attitude's predictive importance: Students with better attitudes toward science are more likely to enroll in more (and higher-level) science courses, and are more likely to perform well on achievement measures.

Classroom Effects on Attitude

Kahle (2006) and Ornstein (2006) examined the effects of the classroom environment and activities therein on student attitudes and perceptions of science. Kahle in this context specifically addresses physics-first, measuring its effects on the classroom as a whole. She used the Constructivist Learning Environment Survey (CLES) to measure the extent to which student experiences conformed to the constructivist view of science learning, which, according to Kahle, holds that "meaningful learning is a cognitive process in which students make sense of new material in light of previously learned material." The CLES consists of five scales, each comprised of six five-point Likert-type items. The five scales are called "Relevance," "Uncertainty," "Critical Voice," "Shared Control," and "Negotiation." The survey was administered to 103 freshman high school students, 66 in a physics class, 37 in a biology class. Kahle disaggregated the scores by sex, finding that boys in physics-first classes perceived significantly more shared control than their peers in freshman biology classes. For girls, the reverse was true in regard to shared control, but the girls in physics-first classes perceived greater relevance than their peers in freshman biology classes.

Ornstein (2006) looked at the effects of the nature of classroom work on student science attitudes generally. He administered questionnaires to 38 teachers and 705 students in middle and high schools. The teacher questionnaire focused on kinds and frequencies of class activities (e.g. lab work, lecture, problem solving), as well as on student characteristics, and the student questionnaire included five five-point Likert-type items covering the same ground as the teacher survey (for confirmation purposes) and 18 five-point Likert-type items assessing student attitude toward science. The attitude items were grouped into three factors: interest in science class and activities (five items), self-confidence in science (five items), and interest in extracurricular science (eight items). The classes were divided into two groups based on frequency of student laboratory work, and group scores compared for both the individual attitude items and the three groupings. The results of this study were ambiguous with respect to the relationship between frequency of laboratory work and attitudes, but did show improved attitudes when laboratory work was more inquiry-based.

Evidence thus suggests that curriculum revisions in science, especially those emphasizing constructivist principles and inquiry-oriented experiments, can improve student attitudes toward science. As the laboratory-oriented nature of high school physics lends itself more easily to these constructivist and inquiry-based approaches, moving it to the beginning of the high school sequence may improve these attitudes and lead to more advanced coursework and better performance.

Attitude and Understanding of the Nature of Science

Gilroy (2002) examined students' and their parents' understandings of the nature of science in conjunction with their attitudes toward science. She used data from interviews with 2,131 public school students (with an oversampling of minority students) and 710 public school parents (125 of whom were minorities) to analyze student and parent attitudes and beliefs. Gilroy found that students and parents who have significant misunderstandings of the nature of science are more apprehensive toward it, resulting in more negative attitudes toward science and, most importantly, minimal coursework attempted in those areas. This may indicate that a reasonable understanding of the nature of science is, in some sense, a prerequisite for adequate coursework. In the same study, she found that these misunderstandings and apprehensions are more commonly found in minority students and their parents. This is likely to exacerbate the achievement gap between minority and non-minority students.

Attitude and Achievement

Several studies investigated the effects of a variety of treatments on both attitude and achievement. Simpkins, Davis-Kean, and Eccles (2006) used data collected from 227 Michigan students in their 5th-, 6th-, 10th-, and 12th-grade years as part of a longitudinal study. The data included information on students' participation in math and science activities, various aspects of student attitudes toward

math and science (interest in and belief in the importance of, and beliefs regarding their own abilities), and their math and science coursework in high school. MANOVA and associated post hoc tests revealed only that boys spend less time on math than do girls and that boys have greater belief in their own math ability than do girls. Many statistically significant relationships were found in binary correlations of the variables, so these were used to develop structural equation models positing differing relationships among the variables when the different aspects of attitude toward math and science were inserted. For science, all three tested aspects of attitude were directly affected by earlier science activity preparation, and had a direct effect on the number of courses taken. Beliefs regarding the importance of science was the only aspect of attitude directly affected by parental education, and only beliefs regarding students' own abilities affected science grades. By contrast, in math, all three aspects of attitude were directly affected by both activity preparation and sex. Interest and belief in one's own math abilities affected both grades and number of courses taken, while attitude toward the importance of math affected neither.

Parker and Gerber (2000) examined the effects of a five-week academic enrichment program on the science achievement and attitudes toward science of 11 minority students from disadvantaged families in rural Georgia. They used a 15-item criterion-referenced pretest and posttest to measure scientific achievement, and the Attitudes Toward Science Survey (Slate & Jones, 1998) to measure student attitudes. This study showed that a small-scale, targeted intervention program can improve not only science achievement, but also attitude toward science. Kiboss, Ndirangu, and Wekesa (2004) similarly studied the introduction of a new mode of learning, in this

case, computer simulation, into a high school biology course. One-hundred-two Kenyan students were randomly selected from their high school biology classes to receive differentiated instruction in the form of the computer simulations on the process of cell division. The researchers used a pretest-posttest design to evaluate achievement, but divided the experimental group of students in half, giving only half the pretest, to control for any confounding effect the pretest may have had on student achievement. They also used two instruments to measure student attitudes toward science, with a total of 45 Likert-type items. The researchers found that the group exposed to the computer simulation made a greater average gain in both achievement and attitude from pretest to posttest than the group that was not, and that the posttest scores of the two treatment groups were not significantly different from one another.

Evidence appears to suggest that treatment programs can be effective in improving student attitude and achievement in science and math. The work of Simpkins, Davis-Kean, and Eccles (2006) is especially interesting in this light, as it indicates that earlier participation in science activities can increase students' beliefs in their own abilities in science, which can in turn improve their science grades. The inversion of the science curriculum can be seen as a treatment which effectively increases earlier participation in physics, which has traditionally been seen by students as the most challenging and intimidating of the sciences. Because of this, one should expect that effects of the inverted sequence would include a better attitude toward physics, and toward science generally, and thus greater achievement in science.

Achievement

A number of studies have examined how curricular methods may affect student science achievement. Tyler-Wood, Mortenson, Putney, and Cass (2000) examined the results of a two-year curriculum realignment for gifted students. They identified 8th-graders preparing to enter a particular high school in Georgia as potential participants if they scored in the 90th percentile or better in math and science on the Iowa Tests of Basic Skills and passed a battery of six other instruments. Of the 48 students who qualified, 32 were selected by a team to participate. The 32 participants were each paired with similarly gifted students at nearby high schools based on a variety of academic and demographic characteristics. These students became the control group, with no change in their curriculum. The experimental group took the revised two-year science and math curriculum. After the two years, both groups took the science and math sections of the ACT. The experimental group performed significantly better on both sections and all included subtests. The researchers also collected qualitative data by videotaping 10 class sessions each in the experimental classroom and five of the classrooms that included control-group students. The tapes were rated at three-minute intervals for the types of activities being used. Teachers in the control classrooms were found to use lecture methods 20% more than those in the experimental classrooms, which used more hands-on activities. Two years later, as follow-up, SAT scores for 28 of the 32 pairs of students were compared. Students in the experimental group were found to score higher on the mathematics area and in total score, with no significant difference on the verbal area.

On the classroom level, Lord and Orkwiszewski (2006) looked at the effects of less-guided instruction in science laboratories on achievement (as opposed to Ornstein [2006], who looked only at attitude). They divided 100 college freshmen enrolled in introductory biology into four laboratory sections, two of which (the control group) were taught in a didactic style, and the other two of which (the experimental group) were taught in an open-ended, inquiry style. Weekly quizzes showed higher achievement by students in the inquiry-style laboratory sections.

Slykhuis and Park (2006) studied computer-based course delivery in high school physics at five North Carolina high schools. In their study, students taking a high school physics course were taught a two- to four-week kinematics unit either in a computer-based laboratory in a school classroom with their teacher (n = 95) or entirely online, with no help from their teachers (n = 55). The researchers regressed a pre-test achievement score on several independent variables, including demographic variables, prior experience in math and science, and several variables relating to computer use (e.g., frequency of use, comfort with computers) using a stepwise multiple regression. This regression was done on the group as a whole, then separately for the classroom and online groups, and finally separately by sex. For the entire group, the strongest correlates to the post-test score were the pre-test score and the current math course they were taking. Sex was a weak correlate. For both of the two groups disaggregated by course delivery type, the pre-test score was the only common significant predictor of post-test score. Current math course and school were significant for the classroom-based group, and sex was significant for the online group. As for the whole group, the pre-test score and current math class were the only significant predictors of post-test

score for the male group. Those two as well as several other variables were significant for the female group: last completed math class, year in school, ethnicity, and comfort with computers.

Changes in curriculum and pedagogy can affect achievement; therefore, one might also expect the change to a physics-first program to have some effect. This expectation is made stronger when one considers that a physics course for high school freshmen must necessarily be pedagogically different from one for juniors and seniors, as freshmen will not have the same level of mathematics available to them. Sheppard and Robbins (2002) point out the discrepancy between the extent of laboratory work in physics called for by the Committee of Ten—half of class time—and the proportion of class time currently devoted to laboratory work: less than 30% in introductory courses, and about 20% in Advanced Placement courses. Their explanation for this is that physics is not being taught as a science, but as "applied mathematics" (p. 430). Moving physics to the freshman year would, in their estimation, force freshman physics teachers to adopt a more lab-centered methodology, which is supported by physics education research as more effective for fostering student learning (e.g., McDermott & Redish, 1999).

School-Level Changes

Considering the broader school level, Dexter, Tai, and Sadler (2006) studied the effects of a traditional school day versus a block-scheduled day on instructional practices and on preparation for college science. They surveyed 8,178 first-semester

science students across 55 four-year colleges and universities about their high school science experiences. Students were asked about the frequency of laboratory work, lecture, and peer tutoring in their high school, as well as what kind of scheduling they had at their high school (traditional, 4-block, 8-block, or other). The researchers did not find any significant differences among the schools on any of the frequency variables based on the school scheduling.

The effects of school-level changes on pedagogy and achievement are therefore doubtful. The shift to physics-first is not necessarily a school-level change, as it directly affects only one department; however, it is a sufficiently large shift that it may be considered to have some of the same characteristics of a school-level change, particularly when it is implemented by building- or district-level administration.

Summary

The theoretical foundations for the physics-first sequence are in place, and have been developed over the last quarter-century. A variety of authors have argued convincingly that the last century of development within biology, chemistry, and physics has resulted in a situation in which the most logical way to build concepts from one science to the next is the opposite of what is currently being done in most high schools. What is lacking is a quantitative study of the effects of such a sequence.

The importance of studying the results of the shift is evident. High-stakes, standardized achievement tests such as the ACT have become increasingly important both for students, due to their impact on college and career possibilities, and for

schools and districts, as they provide evidence of yearly progress that is required under laws such as No Child Left Behind. Failure to show progress can result in negative consequences for the school, up to and including reconstitution. Attitude toward science is an important factor to consider when changing the curriculum because of its demonstrated effects on advanced course enrollment and achievement. This is especially true because so many of the theoretical justifications for the physics-first sequence include an assumption that students will take three years of science (not a requirement in all schools), and that they will consider advanced work in at least one scientific subject Students' understanding of the nature of scientific knowledge is also important, as exams such as the ACT tend to focus on science reasoning skills and interpretation of science information, rather than on content knowledge (ACT, 2007a).

The variables of interest have been studied, attitude most broadly, under a variety of conditions and changes, from simple external or classroom treatments, to broader curriculum revisions, to school-level changes. The physics-first shift falls somewhere between a full school change and a simple curriculum change. It has the potential to involve a major restructuring of an entire academic department, but typically does not have school-wide repercussions (e.g., a change in the school day or class schedule). The present study offers a quasi-experimental investigation that in this case should help isolate some effects of the change, as it is carried out within a department that, as a whole, was otherwise minimally changed by the physics-first pilot program.

CHAPTER 3

METHODOLOGY

Setting

The institution examined in this study is a high school in the south suburbs of Chicago. It is a moderately sized school for the State of Illinois, but relatively small compared to nearby public schools. The communities served by this school are diverse and middle to lower-middle class, with home values in the area averaging $67,000 to $150,000 (reference withheld to prevent institution identification).

The institution began its physics-first program as a pilot program for honor students in the fall of 2002. The program was begun as a pilot for two primary reasons:

- Switching an entire school at once from the traditional to the inverted core sequence puts a tremendous strain on its science department, as there will be two consecutive years in which it offers no (or very few) biology classes and at least double its regular number of physics classes. This results in biology teachers needing to teach physics, which can weaken both staff morale and quality of instruction (Bardeen, 2002).

- The school's administration is committed to a "do no harm" philosophy of curricular reform, and wished to have some experience with the program before making a full commitment.

After two years of the pilot with the honor students, the institution began offering the inverted sequence to all students. In the most recent school year, about two fifths of honors students and about one tenth of non-honors students elected to enroll in the inverted sequence. For this study, data were obtained for five classes of students, from the class graduating in 2006, through the class graduating in 2010.

Participants

Participants in the study were those students who were enrolled in honors science courses beginning with their freshman year in high school. Student eligibility for honors courses was determined based on science grades in middle school and on teacher recommendations.

The Class of 2006 was the first class offered the choice to participate in the inverted rather than the traditional sequence. Twenty-three percent of students in that class elected to participate in the inverted sequence. In the Classes of 2007 and 2008, thirty percent participated in the inverted sequence, and in the Classes of 2009 and 2010, more than forty percent participated in the inverted sequence.

Data used in this study were collected in the freshman and sophomore years of the Classes of 2007, 2008, and 2009 only. The Class of 2006 was not included in the achievement study because their baseline achievement exam was the Stanford

Achievement Test, which is not vertically equivalent with the *Plan* and ACT tests, which were taken by all students in the 10th and 11th grades, respectively. Later classes took the *Explore* test as their baseline instrument as freshmen, which is vertically equivalent to the *Plan* and ACT. (See Instrumentation - Achievement section below.)

The Class of 2006 was not included in the attitude and understanding of the nature of scientific knowledge analysis because data collection on these instruments did not begin until these students were sophomores. The Class of 2010 was not included because these students had only completed their freshman year when data collection ended.

The total number of students sampled (from both sequences) was 185. Of these, 121 (65%) took the traditional sequence of courses, and 64 (35%) took the inverted sequence. In the Class of 2007, 47 students (70%) took the traditional sequence, and 20 (30%) took the inverted sequence. In the Class of 2008, 42 (70%) took the traditional, and 18 (30%), the inverted. In the Class of 2009, 32 (55%) took the traditional, and 26 (45%), the inverted.

Instrumentation

Achievement

Overview

Science achievement data were collected by the school as part of its local assessment program. The district uses the *Explore*, *Plan*, ACT series of tests to assess student achievement. The *Explore* test was given during the freshman year, the *Plan* during the sophomore year, and the ACT during the junior year.

The *Explore*, *Plan*, and ACT tests are the three components of ACT's Educational Planning and Assessment System (EPAS) (ACT, 2007a). The ACT is a very important exam for both student college admissions, and for Illinois high school accountability measures per the State's implementation of the No Child Left Behind law. The *Explore* and *Plan* tests are designed to be vertically equivalent to the ACT test, and have been shown to be good predictors of a student's ACT score (ACT, 2007a).

Each of the three tests has four sections: English, mathematics, reading, and science reasoning. Data used for this study consisted of scores on the science reasoning section, the mathematics section, and the composite. The composite score was arrived at by averaging all four subscale scores (science reasoning, mathematics, English, and reading). The science reasoning subscale score was selected for study because the treatment in question is a change in the science curriculum. The

mathematics section was selected due to the close relationship between science and mathematics, and the composite score was selected due to its ultimate importance in school- and district-level decision making.

The *Explore*, *Plan*, and ACT tests are vertically scaled tests designed for 8th- or 9th-grade students, 10th-grade students, and 11th- or 12th-grade students, respectively. The score range expands as students progress through the exams. The score range is 1–25 for the *Explore* test, 1–32 for the *Plan* test, and 1–36 for the ACT. Mean gain scores from the *Explore* test to the *Plan* test for the three exams, based on a nationally representative sample of more than 200,000 students, were 1.4 points for the science reasoning section, 2.3 points for the mathematics section, and 2.0 points for the composite score (ACT, 2007a).

Reliability and Validity

The *Explore* and *Plan* tests are nationally used and have been tested extensively. ACT uses Kuder-Richardson 20 (KR-20) coefficients to assess the reliability of each subscale and of the composite score for each of the two forms of the test. For 9th-grade administrations of the *Explore* test, they report reliability coefficients for both forms equal to .84 for the math subscale and .95 for the composite score. For the science subscale, the reliabilities are .79 for Form A and .84 for Form B (ACT, 2007b).

For 10th-grade administrations of the *Plan* test, they reported reliabilities for the national sample, and separate reliabilities for the college-bound sample. Because

the present study involves honors students, the college-bound sample is more applicable. KR-20 reliability coefficients for this sample are .83 for the science subscale, .80 for the math subscale, and .94 for the composite score.

ACT (2007b & 2007c) provides a variety of evidence for the validity of the *Explore* and *Plan* tests. Content validity is ensured by aligning items with state curriculum standards and approved textbooks and consulting with teachers to "…ensure that the test content is representative of current high school curricula," (ACT 2007c, p. 40). They also show that the three tests in the EPAS series are related by correlating subscale and composite scores among the three. These correlations range from .53 to .80. Finally, they demonstrate for the *Plan* test that subscale scores increase with increasing student coursework in the relevant subject, and for both the *Explore* and *Plan* tests that subscale scores were significantly positively correlated with student classroom grades.

Survey Instruments

Attitude toward science

Student attitudes toward science were measured by the 14-item Attitude Toward Science in School Assessment (Germann, 1988). This instrument was selected primarily for its focus on attitude toward science in school, as opposed to attitudes toward science's broader role in society, for example, or toward scientists as people. This was considered to be the most important aspect of attitude toward

science when considering the implications of student attitude on decisions regarding future coursework. Because this instrument would be combined with another instrument (on the understanding of the nature of scientific knowledge—see next section) and taken in class, it was important that it be brief but reliable. In four field tests of the instrument with students taking either biology or physical science in grades 7–12, values for Cronbach's alpha ranged from .95 to .97. Construct validity for the instrument was determined by a panel of three judges.

Two minor modifications were made to the instrument:

- The original assessment tool contained 10 positively worded items and four negatively worded items. The wording of three of the items was altered so that there would be seven of each type.
- In the original instrument, students responded on a five-point Likert response scale. For the present study, this was modified to a six-point response scale to eliminate the "neither agree nor disagree" response.

Understanding of the nature of scientific knowledge

Student understanding of the nature of scientific knowledge was measured by a short version of the Nature of Scientific Knowledge Scale (NSKS) (Rubba & Andersen, 1978). This instrument was selected because it is a frequently cited measure of student understanding of the nature of scientific knowledge, and because of its reported reliability. All reported values of coefficient alpha for high school biology, chemistry, and physics students were between .74 and .77. Coefficient alpha

was considerably lower for 9th-grade general science students (.65) and higher for 12th-grade advanced chemistry students (.89). Reliabilities for advanced students in other sciences were not reported. A panel of experts judged the instrument for content validity. Construct validity was established by administering the instrument to two groups of college freshmen expected to score differently on the scale: One group completing an introductory philosophy of science course, and the other completing a biology course for non-science majors. Those completing the philosophy of science course were found to have significantly higher scores on the instrument ($p = .018$).

Rubba and Andersen's original instrument included 48 items: eight each on six subscales. Because this was to be appended to the end of the attitude instrument, and so that students would not have to complete an overly long instrument, only one-quarter of the items on this instrument were used, using one positively worded and one negatively worded item from each subscale for a total of 12 items on the instrument. As with the attitude instrument, the five-point Likert response scale for the items was changed to a six-point scale to remove the "neutral" response.

Both the attitude and the NSKS instruments were administered to students no more than twice per school year, resulting in three to five administrations for each of the three classes used in the study (the Classes of 2007–2009).

Procedures

Institutional Review Board Approval

After discussions regarding data collection and student confidentiality with administration and teachers at the participating school, a proposal to the Northern Illinois University Institutional Review Board (NIU IRB) was drafted. The proposal included a description of the study as agreed to by the school, along with a parental consent form, assent script, and copies of the final survey instrument. The proposal was approved with no modifications. Parental consent forms were provided to the school. They were distributed and collected by the science department chair. Teachers tracked student remission of forms, and advised the survey administrator when a student's consent form had not been returned. Those students (three) were excluded from the study.

Data Collection

Achievement Data

Achievement data were compiled in Microsoft Excel by school personnel. Students were identified solely by school identification number to ensure confidentiality. Data that are relevant to the present study include composite scores, as well as science reasoning and mathematics subscale scores for both the *Explore* and

Plan tests. Other achievement data will be made available for follow-up studies as described in Chapter 5.

Attitude and NSKS Data

The combined attitude and NSKS instrument was administered in students' science classes: once in the fall, and once in the spring. Survey administration occurred either at the beginning of the science class period, or in the last ten minutes. Administration was carried out primarily by the researcher. When that was not possible (e.g., more than two participating classes were meeting simultaneously), the researcher would administer the survey to two classes, and the department chair would administer the survey to the other(s). Surveys were never administered by the students' teachers.

Data Analysis

Achievement Gain

A gain score was computed for each student on each subscale and on the composite score by subtracting their *Explore* score on a subscale (or composite score) from their *Plan* score on the same scale. Examination of the data revealed one case to be an extreme negative outlier on all three achievement measures, with standardized gain scores ranging from –2.82 on the science subscale to –6.10 on the composite

subscale. This case was removed from the data. A two-factor ANOVA was then carried out using the between-subjects factors "program" (traditional vs. inverted) and "cohort" (expected year of graduation).

Attitude Toward Science and NSKS scores

Because the attitude and NSKS instruments were administered twice per year, more time points were available, making growth modeling possible. Hierarchical Linear Modeling (HLM) was used to compare the growth in both attitude and understanding of the nature of scientific knowledge of students in the traditional and inverted programs.

For both the attitude scale and the NSKS scale, a two-level linear growth model was used, with equations (1–3):

Level 1 Model:

$$Y_{ti} = \pi_{0i} + \pi_{1i}(\text{TERM}_{ti}) + e_{ti} \quad (1)$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01}(\text{PROGRAM}_i) + r_{0i} \quad (2)$$

$$\pi_{1i} = \beta_{10} + \beta_{11}(\text{PROGRAM}_i) + r_{1i} \quad (3)$$

In this system of equations, Y_{ti} represents the outcome variable (attitude or understanding of the nature of scientific knowledge) for a given student i at a given time t. It is in the form of a linear function of time with intercept π_{0i} and slope π_{1i}. The variable TERM_{ti} here represents time, and is centered with $\text{TERM}_i = 0$ representing the end of the sophomore year, and previous measurements occurring with a frequency

of twice per year. The first measurement, at the beginning of the freshman year, is thus indexed at $\text{TERM}_i = -3$. The e_{ti} term is the error around the overall slope for student i at time t, which will vary randomly for each student.

The intercept and slope for each individual student, π_{0i} and π_{1i}, respectively, can themselves be described as linear functions of the science programs in which students are enrolled. (In these equations, $\text{PROGRAM}_i = 0$ represents the traditional sequence; $\text{PROGRAM}_i = 1$, the inverted sequence.) β_{00} and β_{01} are the estimated intercept and effect of PROGRAM, respectively, on the Level-1 intercept π_{0i} across all students. A significantly non-zero β_{01}, therefore, represents an overall difference in mean score between students in the two programs at the end of their sophomore year. Likewise, β_{10} and β_{11} are the estimated intercept and effect of PROGRAM, respectively, on the Level-1 slope π_{1i} across all students. A significantly non-zero β_{10} indicates an overall change in the outcome score over time; a significantly non-zero β_{11}, an overall difference in slope between the two programs. The individual-level errors in π_{0i} and π_{1i} are represented by r_{0i} and r_{1i}. They are a measure of the variability across individuals on the intercept and slope, respectively, and can be removed to fix the effects of the Level-2 variable if they are not significantly non-zero.

CHAPTER 4

RESULTS

Research Question 1: Achievement Gain

Research Question 1: Are there differences in achievement gain in science, mathematics, or overall, over the first two years of high school, between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

Two-Factor ANOVA

Achievement data were available for 174 honor students from the Classes of 2007, 2008, and 2009. Of these, 112 took the traditional sequence of courses, and 62 took the inverted sequence. Table 1 shows the mean science and math subscale raw scores and gain scores, and the mean composite raw scores and gain score by program. The students who self-selected into the inverted sequence had slightly higher baseline scores on the science and math scales, resulting in a higher composite score.

The results of the two-factor ANOVAs on the two subscales and the composite score are shown in Table 2. The only statistically significant result at the standard

alpha level of .05 is the positive effect of the inverted program on the composite achievement gain score. Closer examination, however, will reveal that this is most likely a conflating of the effects of the inverted program on the Science and Math subscale scores. It should also be noted that the effect sizes for all three of these effects are considered "small" using Cohen's (1988) criterion ($.02 < \eta^2 < .06$).

Table 1

Explore, *Plan*, and Gain Score Means by Program

	Sequence	Science	Math	Composite
Explore				
	Traditional	19.28	19.12	18.95
	Inverted	20.13	20.65	19.82
Plan				
	Traditional	20.60	21.53	21.05
	Inverted	22.37	23.90	22.67
Explore-to-Plan gain				
	Traditional	1.42	2.26	2.15
	Inverted	2.14	3.22	2.76

Table 2

ANOVA Results for Achievement Gain by Program and Class

		F	*df*	*p*	η^2
Science					
	Program	3.666	1	.057	.023
	Class	1.022	2	.362	.013
	Program × Class	0.025	2	.975	<.001
Math					
	Program	3.445	1	.065	.021
	Class	0.030	2	.970	<.001
	Program × Class	0.094	2	.910	.001
Composite					
	Program	3.940	1	.049*	.024
	Class	0.131	2	.877	.002
	Program × Class	0.480	2	.620	.006

*Significant at $p < .05$.

Research Question 2: Attitude Toward Science

Research Question 2: Are there differences in the growth trajectories in attitude toward science through the first two years of high school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

Reliability

A reliability analysis was run on the revised version of Germann's (1988) attitude scale. Scores on this revised scale showed high internal consistency (Cronbach's $\alpha = .962$).

Hierarchical Linear Modeling

An unconditional linear model using full maximum likelihood estimation was posited first to assess the extent to which the slopes randomly varied with time (centering on the final time point, which was spring of students' sophomore year). Table 3 shows the mean attitude scores by program for each time point. The slopes were found to vary randomly ($\chi^2(155) = 310.7$, $p < .001$), so the linear random effect term, r_{1i}, was retained in later models. Next, a quadratic time term, centered on the final measurement point, was added to the level-1 model, and the new model was compared with the linear model. The quadratic term did not account for any

significant additional variance beyond the linear model ($\chi^2(4) = 4.70$, $p = .318$), so it was removed and a linear model was retained.

Table 3

Attitude Score Means by Program and Time Point

	Sequence	9th grade fall sem.	9th grade spring sem.	10th grade fall sem.	10th grade spring sem
Attitude					
	Traditional	4.76	4.23	4.21	3.83
	Inverted	4.84	4.56	4.37	4.31

After it was determined that the random-effect linear model of attitude growth was superior to both the fixed-effect linear model and to the quadratic model, the program terms were added to level 2 of the random-effect linear model to carry out the final analysis. The model showed no effect of program, either on student attitudes toward science in grades 9 and 10 (measured by β_{01}), or on the linear growth (which in this case was negative) of student attitude toward science over time (measured by β_{11}). As shown in Table 4, the only statistically significant coefficient of interest was β_{10}, the linear change over time. The significant negative value indicates that student attitude toward science declined over time. The r_{1i} term still exhibited significant variance ($\chi^2(154) = 307.4$, $p < .001$), suggesting that student growth in attitude toward science is not uniform, but that this variation in growth was likely not due to their

sequence of science courses. Figure 1 shows a random sample of predicted student attitude growth trajectories.

Table 4

Hierarchical Linear Modeling Coefficients for Student Attitude Toward Science

Coefficient		*t*	*df*	*p*
	β_{01}	–0.920	178	.359
	β_{10}	–5.558	178	<.001**
	β_{11}	0.908	178	.366

**Significant at $p < .01$.

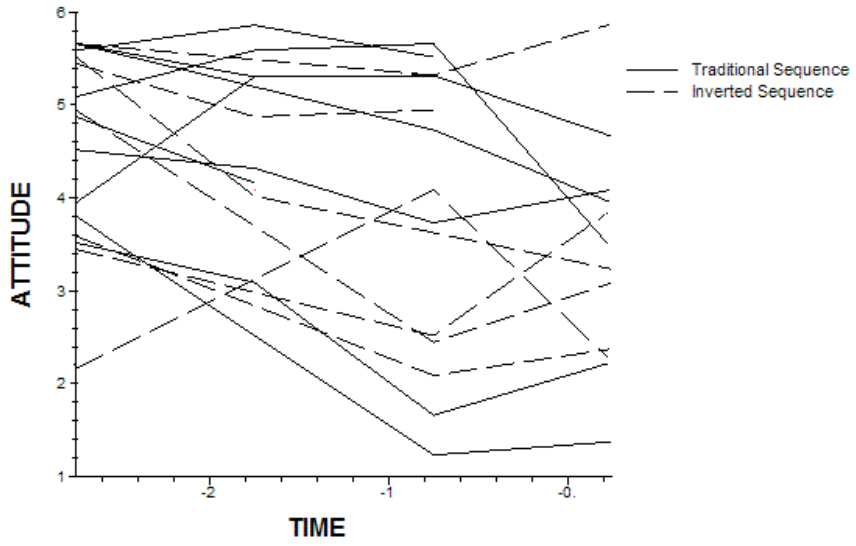

Figure 1. Sample of Predicted Growth Trajectories for Student Attitude Toward Science

Research Question 3: Understanding of the Nature of Scientific Knowledge

Research Question 3: Are there differences in the growth trajectories in understanding the nature of scientific knowledge through the first two years of high school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?

Reliability

The observed reliability on the revised NSKS was weak (Cronbach's $\alpha = .474$). To make some attempt to remedy this, four items with particularly poor item-total correlations ranging from –.024 to .056 were removed from the scale. The internal consistency of scores on the resulting eight-item scale was still less than adequate (Cronbach's $\alpha = .607$), but improved. For this reason, both effects and non-effects of time and course sequence on NSKS score must be interpreted with caution.

Hierarchical Linear Modeling

An unconditional linear model using full maximum likelihood estimation was posited first to assess the extent to which the slopes randomly varied with time (centering on the final time point, which was spring of students' sophomore year). Table 5 shows the mean NSKS scores by program for each time point. The slopes were found not to vary randomly ($\chi^2(154) = 147.0$, $p > .5$), so the linear random effect

term, r_{1i}, was removed in later models. Next, a quadratic term, centered on the final measurement, was added to the level-1 model, and the new model was compared with the linear model. The quadratic term did not account for any significant additional variance beyond the linear model ($\chi^2(3) = 2.05$, $p > .5$), so it was removed.

Table 5

Nature of Scientific Knowledge Scale (NSKS) Score Means by Program and Time Point

	Sequence	9th grade fall sem.	9th grade spring sem.	10th grade fall sem.	10 grade spring sem
NSKS					
	Traditional	4.31	4.05	4.41	4.22
	Inverted	4.29	4.42	4.47	4.59

After it was determined that the fixed-effect linear model of attitude growth was superior to both the random-effect linear model and to the quadratic model, the program terms were added to level 2 of the fixed-effect linear model to carry out the final analysis. As shown in Table 6, the model used to analyze student understanding of the nature of scientific knowledge showed no effect either of time (measured by β_{10}) or of program on either student understanding in grades 9 and 10 (measured by β_{01}), or on the linear growth of student understanding over time (measured by β_{11}). Figure 2 shows a random sample of predicted NSKS score growth trajectories.

Table 6

Hierarchical Linear Modeling Coefficients for Student Understanding of the Nature of Scientific Knowledge

Coefficient		*t*	*df*	*p*
	β_{01}	1.35	178	.179
	β_{10}	1.74	475	.082
	β_{11}	0.806	475	.421

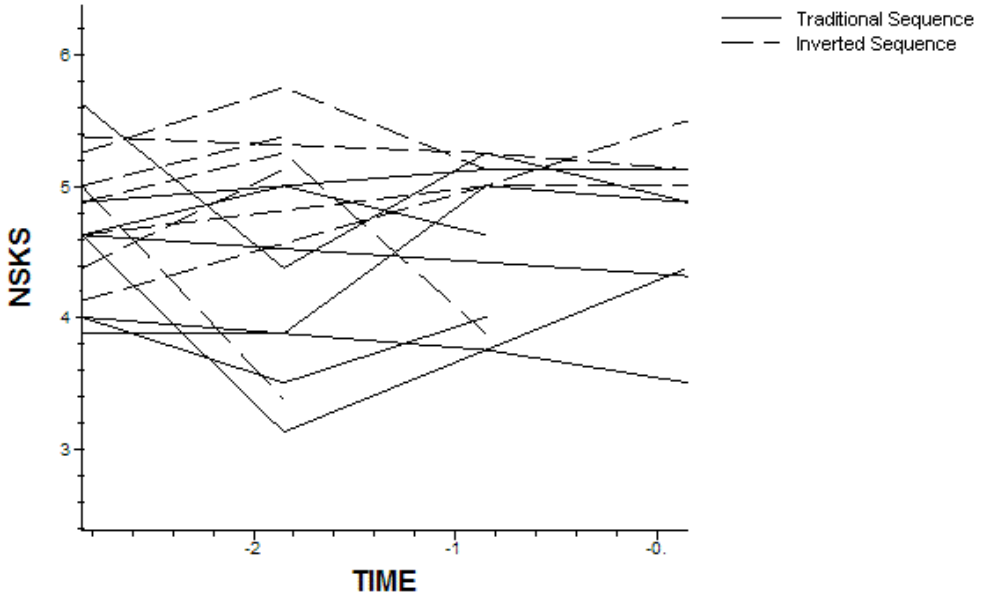

Figure 2. Sample of Predicted Growth Trajectories for Student Understanding of the Nature of Scientific Knowledge

CHAPTER 5

DISCUSSION

Results

Research Question 1: Achievement Gain

To address Research Question 1, "Are there differences in achievement gain in science, mathematics, or overall, over the first two years of high school, between students who took the inverted sequence of courses and those who took the traditional sequence of courses?" a two-factor ANOVA was carried out, comparing program sequence groups and cohorts. The results of the analysis revealed stronger gain in composite achievement scores for students in the inverted (physics-first) sequence of courses. The evidence for positive effects of the inverted sequence on achievement gain is certainly not overwhelming, but it is encouraging for the program and for future work investigating it, especially because the program is quite young. The inverted sequence had a statistically significant effect on one outcome only—the composite *Explore* to *Plan* gain score; however, the composite score (on the ACT) is the one primarily used by colleges, school districts, and state boards of education to make critical decisions affecting students, schools, and districts, so it is clearly the

most important of the three scores. It may be tempting to consider dismissing the significance of the composite score because it combines the non-significant effects of both the science and math subscale scores, but I think that would be an error. The effect sizes for all three gains were similar (as were the significance values). All were small effects by Cohen's (1988) criterion; however, they were effects nonetheless, and the effects may have been limited to some degree by the homogeneous nature of the sample (i.e., consisting solely of honor students; see discussion of limitations below). Data from additional cohorts of students would do much to clarify the nature of this effect. Further, additional analyses that include student ACT scores would double the duration of the study and allow for the possibility of more-sophisticated growth modeling techniques.

Research Question 2: Attitude Growth

To address Research Question 2, "Are there differences in the growth trajectories in attitude toward science through the first two years of high school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?" a multilevel growth model was constructed and compared across program groups The results of the analysis did not show any significant differences in final status or growth between program groups. The results point to two conclusions regarding attitude toward science: There is significant attitude growth variation among students over time, but that variance is not due to participation in a physics-first or biology-first science program; and student attitudes

toward science generally decline through the first two years of high school. The latter conclusion is discouraging, particularly as this study involved science honor students, whom one might expect would be more engaged and interested in science as they learned more about it. The significant variation in growth is, however, healthy, as students early in their high school careers start to make decisions about what topics interest them for advanced study in high school and college.

Research Question 3: Understanding of the Nature of Scientific Knowledge

To address Research Question 3, "Are there differences in the growth trajectories in understanding the nature of scientific knowledge through the first two years of high school between students who took the inverted sequence of courses and those who took the traditional sequence of courses?" a multilevel growth model was constructed and compared across program sequence groups. The results of the analysis did not appear to show any significant differences in final status or growth between program groups. Unfortunately, the weak reliability of the abridged NSKS scale makes interpretation of these results a tentative matter, but results appear to show little difference in the final status or growth between the two groups. Here, unlike for attitude toward science, the overall growth coefficient is positive, meaning that students are acquiring a better understanding of the nature of scientific knowledge as they progress through their first two years of high school. Although there is a trend ($p < .10$), there is not significant linear growth over time. Also, the data do not show significant variance in the linear growth trajectories among students, either within or

between programs, so perhaps this understanding can be attributed to a generally maturing understanding of more abstract concepts regarding science.

Limitations of the Research

Sample Characteristics

One limitation of this study comes from the fact that all participants were honor students. This may have had several different effects on the study. Perhaps most important is the resulting small sample size. Because honor students constitute a very small proportion of the total number of students, only a small number of students were involved in the study, and data from multiple cohorts had to be combined in order to have sufficient data for meaningful statistical analyses. Further, time limitations of the study meant that the data available for the three classes of students were only available for their freshman and sophomore years of high school. Scores from students' junior and senior years could provide evidence of curricular effects on achievement, knowledge, or attitude that are latent, and not yet apparent due to the short time span involved.

Another difficulty in working with data from strictly honor students is the potential homogeneity of the sample. These are students who have been selected by their mid-level teachers as the most likely to succeed in high school honor courses, so one might expect their achievement to show less variability than that of a general population of students. This may be some of the reason for the small effect size in the

achievement data, and also for the lack of variability in growth trajectories in understanding of the nature of scientific knowledge. It seems surprising that science honor students were not also more homogeneous in their attitudes toward science, but perhaps that variability is a result of student placement (into honor-level courses) by teachers, rather than by students themselves selecting the courses in which they wanted to attempt more challenging work.

Finally, working with honor students in any field leaves one vulnerable to the possibility of ceiling effects. These would primarily be considered in the area of achievement, but they have the potential to arise on any of the three measures used in this study. In the case of achievement, students are already scoring near the top of achievement measures in order to be placed into an honor section, so their potential for growth on the same instrument, which is intended for use with the general population of students, is limited. Likewise, it may be expected that students placing into honor sections of science courses already have a reasonably high understanding of the nature of scientific knowledge, or a better-than-average attitude toward science based on positive prior experiences with it.

Remedies

There are two remedies to the limitations described above, and both are currently being utilized: time, and broadening the sample pool. I am continuing to collect data from the honor students This will allow a more thorough longitudinal study of achievement which will allow computation of growth trajectories for the

achievement variables and will increase the stability of the growth estimates for attitude toward science and understanding of the nature of scientific knowledge than did two scores. It will also allow more time points to be collected on the attitude and NSKS measures. Also, the school examined in this study has recently opened up the physics-first option to the general population of students. This will allow the collection of data on a more heterogeneous sample, which will lead to a more thorough understanding of the program's effects. Unfortunately, only about 10% of the non-honors students elected to take the physics-first sequence in the first year it was offered, potentially creating a selection bias, but if the program experiences growth among general students similar to its growth among honor students, there should be a robust sample by the third or fourth cohort.

Duration of the Study

Another limitation of the study was time. This is related to the problem of sample size. Because the analysis was longitudinal in nature, it took four years to collect all of the possible data from one cohort. In the time allotted for the study, this only allowed for complete data collection from one cohort. Unfortunately, that cohort was not large enough to carry out a robust analysis on it alone. The necessity of combining cohorts to increase sample size commensurately limited the time span over which data were available. In a larger population of students, data from three cohorts over two years (or from two cohorts over three years, or one cohort over four years)

may have been sufficient to allow more confident identification of effects and non-effects, but the small number of honor students limited the power of the study.

The availability of data over a longer term may demonstrate program effects that were masked in a two-year study. It also may be that there are effects that are manifested only beyond high school, in choices of college majors or career fields. These also would be shown only by a long-term study.

Remedies

The only remedy for these limitations is adding more observations to better describe change over time. As discussed previously, data collection continues, and it is hoped that later analysis will allow more definitive conclusions about long-term effects. There are currently no plans to study the effects of the program beyond high school, but that has the potential to be another area of interest in future work.

Reliability of Instrument for Measuring Understanding

The questionable reliability of the abridged NSKS limited confidence in the results for of that area of the study. The reliability of the instrument was possibly compromised by abridging it, but it can easily be argued that the abridgment was necessary, both as a courtesy to those teachers who donated their class time to allow their students to complete the surveys, and to limit the effects of survey fatigue in the

students, who might get frustrated dealing with a 62-item instrument (14 attitude items plus 48 NSKS items).

Remedy

When considering an extension of this study that involves measures at additional time points (in addition to the data already collected) it will be difficult to remedy the lack of reliability in future work without invalidating the data already collected for this study. However, one solution being investigated for future studies is online administration of the survey, which might allow more items to be administered and students to take the survey more quickly. This would have the potential to reduce the class time used for the survey, and to lessen survey fatigue, while providing more items, thus increasing the reliability.

Future Research

Extensions of the present study may allow examination of a variety of different aspects of the study. None of these are underway as of now; they are presented as ideas for near-term future work.

Redesign

The significant variation among students in the slopes of attitude toward science was found not to be due to the inverted science sequence nor to student cohort. If this study is carried out again, one should consider including more information that would account for more of the variance in the slopes. This may include effects of teachers, effects of the subject (i.e., biology, chemistry, or physics), effects of classrooms (if the classrooms are sufficiently different that one might have reason to believe they would have different effects on student attitudes). Learning more about why student attitudes vary may help teachers and administrators create conditions in which they are less likely to worsen over time.

Content-Focused Achievement

The EPAS battery of tests (*Explore*, *Plan*, and the ACT) focuses on science reasoning and reading rather than on science content knowledge (ACT, 2007a). An interesting extension of the study would involve a science content assessment. The theory behind physics-first tends to include the often-implicit assumption that, because students will have all three courses as in the traditional sequence, overall content acquisition will be unaffected at worst, and at best enhanced by the introduction of more modern topics into the biology curriculum. This would appear to be a testable hypothesis, requiring primarily the identification and administration of an appropriate instrument.

Participant Satisfaction

The present study assessed growth in student attitude toward science, which could be seen as a proxy for student satisfaction with the program. There are many other participants, however, whose attitudes were not evaluated. Parents and teachers, in particular, are two groups of stakeholders whose satisfaction is critical to the long-term success of such an implementation. Parents could be surveyed and their responses analyzed in a manner similar to that used to measure student attitude, although interviews with parents of both participants and non-participants would also potentially reveal useful information about broader attitudes toward the program. The number of teachers in any given school would be too small to carry out any kind of quantitative study of their satisfaction; however, interviews would be an appropriate way of assessing satisfaction with the new course sequence.

Self-Selection

Related to participant satisfaction is the phenomenon of self-selection. Every participant in the present study made a decision before entering the study to take either the novel physics-first sequence of courses or the traditional biology-first sequence. It would be of use to school and district officials to learn from parents and students about the factors that influenced those decisions. Based on that information, they could potentially offer options which students would be more likely to select, and could more effectively “market” new course or program offerings to students and their

parents. These data would probably be best collected both from a large sample through surveys, and with a more limited sample through interviews.

Further, as the program progresses, enrollment trends could be studied. If done contemporaneously with a participant satisfaction study as described above, this could provide extremely useful information about what factors are related to enrollment fluctuations in an alternate program or sequence such as this.

Long-Term Effects

As mentioned above, there are potential long-term effects of the change in sequence that bear investigation. One could envision effects of the differing sequences on advanced course enrollment rates and achievement in advanced courses; on selection of college major and achievement in introductory college courses; and possibly even on later career choices. Any of these would merit study, though the link to the course sequence will be most evident in studies of decisions and achievement in late high school and early college, rather than in studies of later college and career decisions.

Related Studies and Alternative Methods

The potential for alternative methods of conducting a study of a physics-first program (or programs) exists. These suggestions for future work are not directly related to the present study, but are other areas of work that may be of interest to

future researchers. Ideas are presented here in estimated order of increasing difficulty of implementation.

"Micro-Tests"

The theory underlying the physics-first curriculum is based on the idea that physics principles are helpful for understanding chemistry, and later biology. It should be possible for a teacher, especially a chemistry teacher, to perform small tests of this theory by varying the order of presentation of subjects to see which order results in better achievement outcomes.

As an example, one topic frequently taught early in a high school chemistry course is identification and classification of different types of chemical reactions. This is often taught before applicable physical concepts related to it, such as electron configuration and Lewis structures. One could envision two sections of a chemistry course taught with different topic orders: one in the standard way, and one in which electron configurations and Lewis structures are taught before classification of reactions. The teacher could then examine student work and scores on exams in a systematic way to assess student apprehension of the topics.

Different Physics-First Implementations

There are a number of schools around the country that have implemented a physics-first sequence of science courses in a wide variety of forms. Some co-teach

freshman physics with an introductory algebra course, some require algebra in eighth grade as a prerequisite, and some have no math requirement. Some offer self-selection into the sequence; others mandate it for all freshmen. Some have proposed teaching the introductory physics course in eighth grade to allow students to take an additional advanced science elective as juniors. It would be interesting to identify the variety of different implementations and to develop a way to assess their effectiveness.

Random Assignment of Students

Random assignment of students to a physics-first or traditional sequence of courses within a school would allow for very robust analysis and be important for attributing effects definitely to the physics-first sequence. This would, of course, be very difficult to implement, and would require the commitment of a wide variety of stakeholders: the school district, building administration, teachers, and most of all, parents and students. Studies such as the present study, showing that the effects are neither dramatic nor catastrophic, may lend encouragement to those considering such a study, but such an implementation would nevertheless be quite unlikely.

Conclusion

The results of this study provide mild, but crucial, support for the idea of the physics-first sequence. Although only one of the statistical tests yielded a significant result—the test for the effect of program on the composite *Explore* to *Plan* gain—it

happened to be the most important result on two tests vertically scaled to a test that is high-stakes for both students and their districts. Given the limited sample of students available for this study, it would be a mistake to overgeneralize the results, but they are sufficiently encouraging to provide justification for further work in this area. Such work does continue with a broader population of non-honors students at this school. More participants in each cohort and longer-term collection of data should allow greater insight into this problem. Additionally, showing non-effects for other outcomes may not be encouraging, but neither is it discouraging, and the significantly larger gain in composite score from *Explore* to *Plan* for students in the physics-first sequence may itself be enough to convince other schools and districts to try pilot programs of their own. It is my sincere hope that when they do, they will take the time to plan a careful analysis of their program, so that others may learn from it as well.

REFERENCES

ACT (2007a). *The ACT technical manual.* Iowa City, IA: Author.

ACT (2007b). *The Explore technical manual.* Iowa City, IA: Author.

ACT (2007c). *The Plan technical manual.* Iowa City, IA: Author.

Bardeen, M. G. (ed.). (2002). *ARISE: American Renaissance in Science Education. Implementation resource book: Suggestions from the field.* Batavia, IL: Fermi National Accelerator Laboratory.

Bardeen, M. G., Freeman, W., Lederman, L., Marshall, S., Thompson, B., Young, M. J. (1998). *ARISE: American Renaissance in Science Education. Three year high school science core curriculum. A framework* (M. Perricone, Ed.) (Fermilab Publication No. FERMILAB-TM-2051). Batavia, IL: Fermi National Accelerator Laboratory.

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

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

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

Dexter, K. M., Tai, R. H., & Sadler, P. M. (2006). Traditional and block scheduling for college science preparation: A comparison of college science success of students who report different high school scheduling plans. *The High School Journal, 89*(4), 22–33.

Germann, P. J. (1988). Development of the attitude toward science in school assessment and its use to investigate the relationship between science achievement and attitude toward science in school. *Journal of Research in Science Teaching, 25*(8), 689–703.

Gilroy, M. (2002). Waking up students' math/science attitudes and achievement. *The Education Digest, 68*(4), 39–44.

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

Hake, R. R. (2002). Physics first: Precursor to science/math literacy for all? *American Physical Society Forum on Education Newsletter*, Summer. Retrieved December 1, 2005, from http://www.aps.org/units/fed/newsletters/summer2002/index.cfm.

Hamilton, D. K. (1970). Physics and the high school sophomore. *The Physics Teacher, 8,* 457–458.

Hewitt, P. G. (1990). Conceptually speaking . . . *The Science Teacher, 57*(5), 54–57.

Hickman, P. (1990). Freshman physics? *The Science Teacher, 57*(3), 45–47.

House, J. D. (2004). Cognitive-motivational characteristics and science achievement of adolescent students: Results from the TIMSS 1995 and TIMSS 1999 assessments. *International Journal of Instructional Media, 31*(4), 411–424.

Kahle, J. B. (2006, April). Classroom learning environment: *Using the CLES to monitor the effects of physics-first.* Paper presented at the Annual Conference of the National Association for Research in Science Teaching, San Francisco, CA.

Kiboss, J. K., Ndirangu, M., & Wekesa, E. W. (2004). Effectiveness of a computer-mediated simulations program in school biology on pupils' learning outcomes in cell theory. *Journal of Science Education and Technology, 13*(2), 207–213.

Konstantopoulos, S. (2006, December). Trends of school effects on student achievement: Evidence from NLS:72, HSB:82, and NELS:92. *Teachers College Record, 108*(12), 2550–2581.

Lederman, L. M. (1995). A new high school science curriculum. *Physics Today, 48*(4), 11–13.

Lederman, L. M. (2001a). Physics first. *American Physical Society Forum on Education Newsletter*, Spring. Retrieved from http://www.aps.org/units/fed/newsletters/spring2001/index.cfm.

Lederman, L. M. (2001b). Revolution in science education: Put physics first! *Physics Today, 54*(9), 11–13.

Lord, T., & Orkwiszewski, T. (2006, August). Moving from didactic to inquiry-based instruction in a science laboratory. *American Biology Teacher, 68*(6), 342–345.

Lyons, T. (2005). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education, 36*(3), 285–311.

McDermott, L. C., & Redish, E. F. (1999). Resource Letter: PER-1: Physics Education Research. *American Journal of Physics, 67*, 755–767.

Myers Jr., F. R. (1987). A case for a better high school science sequence in the 21st century. *The Physics Teacher, 25,* 78–81.

National Education Association (NEA). (1893). *Report of the committee on secondary school studies.* Washington, DC: Bureau of Education.

Ornstein, A. (2006). The frequency of hands-on experimentation and student attitudes toward science: A statistically significant relation. *Journal of Science Education and Technology, 15*(3), 285–297.

Palombi, J. (1971). The illogic of teaching bio before chem and physics. *The Physics Teacher, 9,* 39–40.

Parker, V., & Gerber, B. L. (2000). Effects of a science intervention program on middle-grade student achievement and attitudes. *School Science and Mathematics, 100*(5), 236–242.

Pasero, S. (2001). *The state of physics-first programs.* (Fermilab Publication No. Pub-01-206). Batavia, IL: Fermi National Accelerator Laboratory.

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education, 62*(4), 449–458.

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

Simpkins, S. D., Davis-Kean, P. E., & Eccles, J. S. (2006). Math and science motivation: A longitudinal examination of the links between choices and beliefs. *Developmental Psychology, 42*(1), 70–83.

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. *Journal of Educational Research, 95*(6), 323–332.

Slate, J. R., & Jones, C. H. (1998). Fourth and fifth grade students' attitudes toward science: Science motivation and science importance as a function of grade level, gender, and race. *Research in the Schools, 5,* 27–32.

Slykhuis, D. & Park, J. (2006). Correlates of achievement with online and classroom-based MBL physics activities. *Journal of Computers in Mathematics & Science Teaching, 25*(2), 147–163.

Sousa, D. A. (1996). Are we teaching high school science backward? *NASSP Bulletin, 80*(2), 9–15.

Swartz, C. E. (1971). Let's do away with high school courses in earth science, biology, chemistry, and physics. *The Physics Teacher, 9,* 65–66.

Trumper, R. (2006). Factors affecting junior high school students' interest in physics. *Journal of Science Education and Technology, 15*(1), 47–58.

Tyler-Wood, T. L., Mortenson, M., Putney, D., & Cass, M. A. (2000). An effective mathematics and science curriculum option for secondary gifted education. *Roeper Review, 22*(4), 266–269.

Willett, J. B., & Sayer, A. G. (1996). Cross-domain analyses of change over time: Combining growth modeling and covariance structure analysis. In G. A. Marcoulides & R. E. Schumacker (Eds.), *Advanced structural equation modeling* (p. 125- 157). Hillsdale, NJ: Erlbaum.

APPENDIX A

PARENTAL CONSENT FORM

Parental Consent Form

Minor

Your child/ward is invited to participate in a research study on the "physics-first" core sequence of science courses being conducted by Spencer Pasero, a graduate student at Northern Illinois University.

The purpose of this study is to collect information about the effects, if any, of the inverted sequence on students' science achievement, attitudes toward science, and beliefs regarding the nature of scientific knowledge.

Your child's/ward's participation in this study will last through high school. He or she will be asked to complete a 26-item attitude survey about science twice each school year (once in the fall, and once in the spring). Your child's/ward's high school science experience will not be affected in any other way by this study.

We do not anticipate that your child/ward will experience any risk or discomfort as a result of this study. However, participation is completely voluntary, and if your child feels uncomfortable completing the survey, he/she is free to discontinue participation at any time.

Information obtained during this study may be published in scientific journals or presented at scientific meetings, but any information that could identify your child/ward will be kept strictly confidential. Only class-level data will be reported, not data on individual students.

Participation in this study is voluntary, and will not affect the assessment of your child/ward in the involved classes. Your child/ward will be asked to indicate individual assent to be involved immediately prior to participation, and will be free to withdraw from participation at any time without penalty or prejudice.

Any questions about the study should be addressed to Spencer Pasero, c/o Prof. Thomas Smith, ETRA Department, College of Education, Northern Illinois University, DeKalb, IL 60115.

If you wish further information regarding your rights or your child's/ward's rights as a research subject, you may contact the Office of Research Compliance at Northern Illinois University at 815-753-8588.

----------Please cut and submit----------

I agree to allow my child/ward to participate in this research study and acknowledge that I have received a copy of this consent form.

_____ _____

Signature of Parent/Guardian Date

APPENDIX B

ASSENT SCRIPT

Assent Script

To be read immediately prior to survey administration

The survey I am about to give you is part of a research study on the "physics-first" core sequence of science courses being conducted by Spencer Pasero, a graduate student at Northern Illinois University.

The purpose of this study is to collect information about the effects, if any, of the inverted sequence on science achievement, attitudes toward science, and beliefs regarding the nature of scientific knowledge.

You will be asked to complete this survey twice each school year (once in the fall, and once in the spring). Your high school science experience will not be affected in any other way by this study.

Participation in this study is completely voluntary, and if you feel uncomfortable completing the survey, you are free to stop at any time. Your decision whether or not to complete the survey will not negatively affect you. You are free to withdraw from participation at any time without penalty or prejudice.

APPENDIX C

SURVEY INSTRUMENT

Biology-first Physics-first
Grade: 9 10 11 12
Student ID#_____

Attitude Toward Science and the Nature of Scientific Knowledge Survey

Items 1-14 of this survey involve your attitude toward science. Items 15-26 ask for your opinions on various aspects of the nature of scientific knowledge. Please indicate the extent to which you agree or disagree with each of the statements by circling a number from 1 (strongly disagree) to 6 (strongly agree). *Please note: Completion of this survey is entirely voluntary. If you feel uncomfortable at any time, you may stop and retain or discard this survey as you see fit.* Your responses will be seen only by the external researchers, and will be completely confidential. Thank you for your help.

	Strongly Disagree	Moderately Disagree	Mildly Disagree	Mildly Agree	Moderately Agree	Strongly Agree
1. Science is repellent and boring.	1	2	3	4	5	6
2. Science is exciting.	1	2	3	4	5	6
3. Science makes me feel uncomfortable, restless, irritable, and impatient.	1	2	3	4	5	6
4. When I hear the word *science*, I have a feeling of like.	1	2	3	4	5	6
5. I feel at ease with science and I like it very much.	1	2	3	4	5	6
6. During science class, I usually am interested.	1	2	3	4	5	6
7. Science is fun.	1	2	3	4	5	6
8. I would not like to learn more about science.	1	2	3	4	5	6
9. I do not like science and it bothers me to have to study it.	1	2	3	4	5	6
10. If I knew I would never go to science class again, I would feel happy.	1	2	3	4	5	6
11. Science is a topic which I enjoy studying.	1	2	3	4	5	6
12. I feel a definite negative reaction to science.	1	2	3	4	5	6
13. Science is uninteresting to me and I do not enjoy it.	1	2	3	4	5	6

Biology-first Physics-first
Grade: 9 10 11 12

	Strongly Disagree	Moderately Disagree	Mildly Disagree	Mildly Agree	Moderately Agree	Strongly Agree
14. The feeling that I have toward science is a good feeling.	1	2	3	4	5	6
15. Scientific knowledge is unchanging.	1	2	3	4	5	6
16. The laws, theories, and concepts, of biology, chemistry, and physics are not linked.	1	2	3	4	5	6
17. Biology, chemistry, and physics are similar kinds of knowledge.	1	2	3	4	5	6
18. Scientific knowledge need not be capable of experimental test.	1	2	3	4	5	6
19. Scientific knowledge does not express the creativity of scientists.	1	2	3	4	5	6
20. It is meaningful to pass moral judgment on both the applications of scientific knowledge and the knowledge itself.	1	2	3	4	5	6
21. Those scientific beliefs which were accepted in the past and have since been discarded, should be judged in their historical context.	1	2	3	4	5	6
22. Scientific knowledge is stated as simply as possible.	1	2	3	4	5	6
23. Scientific laws, theories, and concepts express creativity.	1	2	3	4	5	6
24. Scientific laws, theories, and concepts are not stated as simply as possible.	1	2	3	4	5	6
25. The evidence for scientific knowledge must be repeatable.	1	2	3	4	5	6
26. Even if the applications of a scientific theory are judged to be good, we should not judge the theory itself.	1	2	3	4	5	6