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## Physics First: Impact on SAT Math Scores

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*Loyola Marymount University*

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Fall October 2013

## Physics First: Impact on SAT Math Scores

Craig Earl Bouma

*Loyola Marymount University*, [craig.bouma@gmail.com](mailto:craig.bouma@gmail.com)

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LOYOLA MARYMOUNT UNIVERSITY

Physics First:  
Impact on SAT Math Scores

by

Craig E. Bouma

A dissertation presented to the Faculty of the School of Education,  
Loyola Marymount University,  
in partial satisfaction of the requirements for the degree  
Doctor of Education

2013

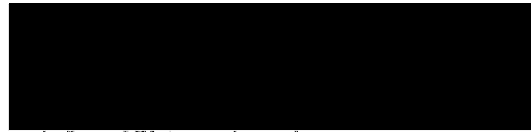
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Impact on SAT Math Scores  
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This dissertation written by Craig Bouma, under the direction of the Dissertation Committee, is approved and accepted by all committee members, in partial fulfillment of requirements for the degree of Doctor of Education.

Date July 29, 2013

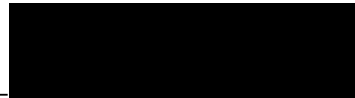
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## DEDICATION

This study is dedicated to my family, dear friends, and fellow Ignatian educators. You all inspire me. I want to work harder and do better because of you. I also have a special place in my heart for all the boys out there that have big imaginations, a knack for tinkering with stuff, and a curiosity to discover how things work. Education has not served many of you well. It has squashed your invaluable curiosity and creativity with butt-in-the-seat classrooms, overly structured lesson plans, irrelevant curricula, well-intentioned though hyper-feminine instructional styles, overly punitive and restrictive classroom management, and misguided measures of achievement that have extinguished your desire to figure out the world with your own eyes, hands, and soul. I hope that educational theory and practice will one day be reformed to optimize learning, skills, and attitudes toward science, for all the underrepresented boys that fall through the cracks from elementary school to college. May your imagination flourish and your creativity soar. May you *all* have the opportunity to learn in environments that “meet you where *you* are” so that learning can be deep and effective. I dedicate this work to those boys.

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## LIST OF ABBREVIATIONS

BCP	Biology first secondary science sequence. Biology is first (introductory and descriptive), chemistry is second, and physics is the terminal science course.
FCI	Force Concept Inventory. A diagnostic exam to measure conceptual understandings of students in Newtonian mechanics.
HSPT	High School Placement Test. The HSPT is given to eighth graders. The math section of the HSPT (HSPT math) was used in the study to establish prior math achievement of the students.
MRHS	Matteo Ricci High School. MRHS is a pseudonym used in the paper for the school under study.
NAEP	National Assessment of Educational Progress.
Non-PF	Students at MRHS that chose to take no science (i.e., physics) as ninth-graders.
PCB	Physics First secondary science sequence. Physics is first (introductory and foundational); chemistry is second, followed by biology.
PF	Physics First. PF designates two things in this dissertation: (a) PF is the common name of a high school curriculum where ninth-graders take physics, 10 <sup>th</sup> -graders take chemistry, and 11 <sup>th</sup> -graders take biology; (b) PF is the independent grouping variable in the study and represents the students that took physics as ninth-graders at MRHS.
PISA	Programme for International Student Assessment. This is an assessment sponsored by the Organization for Economic Cooperation and Development (OECD). Launched in 1997 it aims to evaluate education systems worldwide every three years by assessing 15 year olds' competencies in key areas such as mathematics and science.
TIMSS	Trends in International Math and Science Study

## ABSTRACT

Physics First: Impact on SAT Math Scores

By

Craig E. Bouma

Improving science, technology, engineering, and mathematics (STEM) education has become a national priority and the call to modernize secondary science has been heard. A Physics First (PF) program with the curriculum sequence of physics, chemistry, and biology (PCB) driven by inquiry- and project-based learning offers a viable alternative to the traditional curricular sequence (BCP) and methods of teaching, but requires more empirical evidence. This study determined impact of a PF program (PF-PCB) on math achievement (SAT math scores) after the first two cohorts of students completed the PF-PCB program at Matteo Ricci High School (MRHS) and provided more quantitative data to inform the PF debate and advance secondary science education. Statistical analysis (ANCOVA) determined the influence of covariates and revealed that PF-PCB program had a significant ( $p < .05$ ) impact on SAT math scores in the second cohort at MRHS. Statistically adjusted, the SAT math means for PF students were 21.4 points higher than their non-PF counterparts when controlling for prior math achievement (HSTP math), socioeconomic status (SES), and ethnicity/race.

## CHAPTER 1

### BACKGROUND OF THE STUDY

#### Introduction

Could the majority of high schools in the United States be teaching science backwards? National assessments such as the National Assessment of Educational Progress (NAEP), Programme for International Student Assessment (PISA), and Trends in International Math and Science Study (TIMSS), have consistently ranked American students lower in science and math than their international counterparts. In 2011, only 21% of 12<sup>th</sup>-grade students were proficient in science, and students of color, particularly from urban areas, performed significantly lower on average (National Center for Education & Statistics [NCES], 2011). Students are underperforming in science and mathematics, with many groups of students underrepresented in Science, Technology, Engineering, and Math (STEM) classrooms and careers (National Research Council [NRC], 2011). The current curricular approach may not be optimal for student achievement and it may be time to consider a new approach to secondary science education that advances STEM literacy for *all* into the 21<sup>st</sup> century. This study evaluated an alternative secondary science program known as Physics First (PF—physics, chemistry, biology [PCB]) and explored its impact on SAT math scores.

This study uses acronyms to distinguish the secondary science program and its participants. PF-PCB represents the type of Physics First (PF) program under investigation as opposed to PF—physics, biology, and chemistry (PF-PBC). The traditional sequence in the United States is biology, chemistry, and physics (BCP). In this study students that completed the PF-PCB program are referred to as Physics First (PF) students and their counterparts who chose not

to enroll in ninth grade physics yet completed chemistry and biology are non-Physics First (non-PF) students. Thus, PF is the acronym for Physics First and also represents the group of students under study. PF-PCB represents the type of PF program studied. PCB is the sequence of courses.

### **The Problem and Need for Reform**

Student achievement in science and math in the United States has been a concern for many years. The lack of progress in student achievement suggests that secondary science education needs modernization. Reports like *A Nation at Risk* (National Commission on Excellence in Education [NCEE], 1983), the *Trends in International Mathematics and Science Study* (TIMSS) (Martin, Mullis, & Foy, 2008; Martin, Mullis, Foy, & Stanco, 2012; Smith, Martin, Mullis, & Kelly, 2000), and *The Nation's Report Card* (NCES, 2011) have documented the recent lackluster performance of American students in science. John R. Wilt (2005) argued, "Science education must change—and change soon. The amount of technical information available to humanity doubles every few years, and this information eventually makes its way into the high school science curriculum" (p. 360). The gap between scientific discovery and science education has widened; the pace of change of the former has increased while the latter has remained the same. In order to better prepare a scientifically literate and capable citizenry to meet the challenges and opportunities of the 21<sup>st</sup> century, student achievement in science must improve and student access to science must be addressed. The secondary science programs schools have inherited in the United States need to be questioned and alternative models evaluated.

Modernizing curriculum in secondary science education in the 21<sup>st</sup> century is a necessary component of an effective democracy and vibrant economy (Bybee, McCrae, & Laurie, 2009;



DeBoer, 2010; Martin et al., 2012; Miller, 1998, 2002, 2004; Mueller, Tippins, & Bryan, 2012; NRC, 2007). The collective ability for citizens to understand, participate, and meet the future's pressing scientific challenges in the arenas of public health and the environment requires a new level of "civic scientific literacy" (Miller, 1998, p. 240). A modern, democratic society requires scientifically knowledgeable citizens to function properly. DeBoer (2010) stated "Science as a way of thinking was more suitable for life in a democracy than the more authoritative methods offered by the classics and mathematics because the methods of science allowed individuals to be their own observers of the natural world and to draw conclusions independently based on those observations and the power of their own reasoning" (p. 281). In addition to an informed citizenry, improving STEM education yields a more innovative and vibrant economy. STEM fields are a rapidly growing sector that provides jobs and boosts gross national productivity (NRC, 2007). Thus improving STEM education for the 21<sup>st</sup> century is not only a matter of national security and global competitiveness for the United States, but it is a matter of equipping citizens with a basic level of scientific literacy to face the science, technology and engineering challenges of the future (Miller, 2004).

The lack of acceptable improvement in science and math education outcomes over the last three decades has compelled educators to urgently seek and evaluate alternative curricular models like Physics First (PF-PCB). In *A Nation at Risk* (NCEE, 1983), the National Commission on Excellence in Education warned that American students were unprepared to participate in the rapidly evolving science and technology-based workforce. The TIMSS 2007 report showed that fourth and eighth graders in the US continued to score well below their international counterparts in science (Martin et al., 2008). More recently, the NCES reported in

*The Nation's Report Card: Science 2009* that only 21% of 12<sup>th</sup>-graders performed at or above proficient level in science. Further, students of color (Black = 4%, Hispanic = 8%), particularly from urban areas, performed significantly lower on average than their White (29%) and Asian/Pacific Islander (40%) counterparts (NCES, 2010). While *The Nation's Report Card: Science 2011* reported modest improvements in eighth grade scores, and a slight narrowing of the race/ethnicity gap, underperformance in the US and the racial/ethnic gap persists (NCES, 2012).

According to ACT's (2013) report, *The Condition of College and Career Readiness*, 31% of test takers in the United States met the ACT College Readiness Benchmarks in science and 46% in mathematics. African American graduates were least likely to meet the benchmarks with only 7% meeting the science and 15% meeting the math benchmark. The report also indicated that 16% of Hispanic/Latino test takers met the science and 13% met the math benchmark. Furthermore, the College Board reported in *The Ninth Annual AP Report to the Nation* (2013) that access remains a concern. The College Board presented data showing that among students with high potential for success in Advanced Placement (AP) math course work, only three out of 10 Black/African American and Hispanic/Latino students took any such AP math course.

In *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads* (NRC, 2011), the NRC urged the education community address the wide disparity among racial/ethnic groups. The report showed that minorities in the United States are "seriously underrepresented in science and engineering, yet they are also the most rapidly growing segment of the population" (p. 1). In 2006 these minority groups

“represented 28.5% of our national population but just 9.1% of college-educated Americans in science and engineering occupations” (p. 36).

These reports have challenged the science education community to reform. Addressing when and how science is taught in high school may be a part of the change; the sequence of science courses and methods of instruction can increase access to and performance in science and mathematics. The problems of secondary science are multifaceted and equity and access should be at the top of the list. It is important that reforms in curriculum and instruction are framed in a social justice lens. This study demonstrated that addressing when and how science is taught in ninth through 12<sup>th</sup> grades may address this challenge; a Physics First (PF-PCB) program can increase access to and performance in science and mathematics.

### **Physics First**

The prevailing secondary science education sequence inherited by the current generation is designated in this study as BCP or biology first (biology–chemistry–physics). The inverted alternative, Physics First (physics–chemistry–biology [PCB]), may address the issues faced by the science education community. PCB places an algebra-based physics course at the beginning of the high school curriculum sequence to serve as the foundational course (Grade 9). Typically, 10<sup>th</sup>-grade chemistry and then 11<sup>th</sup>-grade biology follow. This sequence places the major scientific concepts in a coherent and logical order, but this sequence inverts the order in which most high schools teach science.

The roots of the predominant high school science course sequence (BCP) in the U.S. were established well over 100 years ago, and many assert that the time for re-sequencing has come ( Sheppard, 2002; Sheppard & Robbins, 2003, 2009; Vazquez, 2006). Science has

significantly advanced in the last century, especially in the last 60 years with discovery of the structure of DNA (Watson & Crick, 1953). Such breakthroughs resulted in a 21<sup>st</sup> century biology course that is much different than the 20<sup>th</sup> century course. Haber-Schaim (1984) evaluated high school science courses and documented that the typical biology course included a significant amount of cellular and molecular content, in addition to the older botanical and zoological topics. He opined that deeper understandings of modern biology could be achieved with a foundation in chemistry and physics, where the opposite was not true of chemistry and physics concepts, which did not require a foundation in biology. The Biological Sciences Curriculum Study (BSCS) symposium published *The Cornerstone-to-Capstone Approach* (2006) and demonstrated support for the reorganization of the high school curriculum with biology offered last. Cavanaugh (2006) found that modern biology required an understanding of the behavior of molecules, and this chemistry content required a grounding in physics. In Sheppard and Robbins's (2005) historical research on secondary science education, they found that long ago "physics was considered to be the foundational science" (p. 561). Since understanding new information requires prior knowledge of foundational concepts, placing biology after physics and chemistry made sense. Yet, this reasoning incites continuing debate.

The opposition to the Physics First argument for coherence asserts that sophisticated math is needed to learn physics. If high school physics requires sophisticated math, then it should be offered last when student math skills are more advanced. Wilt (2005) countered this assertion and pointed out that "chemistry actually uses more advanced mathematical concepts than physics" (p. 347) and "no pedagogical reason (specifically, lack of mathematical understanding) exists not to teach physics as a first year high school science course" (p. 348). Thus, reordering

the predominant BCP secondary science curriculum by putting biology last and physics first could improve student achievement in science and math in the United States.

Physics First programs in the sequence studied here (PF-PCB) may have had their beginnings in the 1960s or 1970s, but influential physicist Leon Lederman is most often credited with coining the term “Physics First.” Lederman, a 1988 Nobel Laureate in physics, championed Physics First and suggested that schools should invert the traditional high school science sequence from BCP to PCB (Lederman, 2001). Lederman argued that PCB was the logical order and offered a more efficient way of scaffolding science curriculum in high school to meet scientific literacy goals. He asserted physics was conceptually appropriate as an introductory course and urged that age-appropriate materials and more effective methods be developed for ninth-grade physics. Lederman formed the American Renaissance in Science Education project (ARISE) that promoted and created Physics First resources (Bardeen & Lederman, 1998; Lederman, 1998, 2001, 2005).

Arthur Eisenkraft, former President of the National Science Teachers Association (NSTA) from 2000-2001, responded to Lederman’s call by advocating for Physics First and Physics for All (Eisenkraft, 2010) and developed age-appropriate physics materials for PCB, published as *Active Physics* (Eisenkraft, 2005), and funded by the National Science Foundation (NSF). Likewise, the American Association of Physics Teachers (AAPT) endorsed Physics First (2002, 2007) and a number of scientists, education researchers, and curriculum experts followed suit (Glasser, 2012; Hehn & Neuschatz, 2006; Neuschatz, McFarling, & White, 2008; Neuschatz & McFarling, 2003; Pasero, 2003; Wilt, 2005).

Promoters of the Physics First movement argue that physics is a foundational science and therefore a grounding component of a three-year secondary science program. Furthermore, they advocate for chemistry as a central science given the molecular nature of modern biology; mastery of chemistry allows for a richer understanding of 21<sup>st</sup> century biology. The primary argument for PCB remains simple: PCB provides a logical, coherent sequence for 21<sup>st</sup> century learners. In addition, the sequence increases access to physics and the application of math skills earlier in science education. Building upon Leon Lederman's argument for Physics First (Lederman, 2001), Arthur Eisenkraft (2010) advocated for Physics for All as a more equitable learner-centered approach to teaching science in the United States. This push to invert the traditional high school curriculum marked the beginning of the Physics First movement.

Since Lederman's call for change, a number of high schools across the nation have become Physics First schools. Estimates in 2005 showed that 4% of all U.S. high schools had implemented some variation of Physics First (Neuschatz et al., 2008). As more schools consider PCB, a need has emerged to evaluate the efficacy of these Physics First programs in greater depth. Matteo Ricci High School (MRHS), a private, single-sex, high school on the West Coast of the United States, launched its PCB program in 2007 and graduated its first cohort in 2011. This study evaluated the first two graduating classes (cohorts) from MRHS's Physics First program in terms of both student access and student achievement in math.

### **Purpose of the Study**

This study sought to determine the influence of the PF-PCB program at MRHS on SAT math scores to inform the secondary science education community with quantitative evidence needed to further evaluate PCB. Physics First programs have increased across the United States

(Hehn & Neuschatz, 2006; Neuschatz et al., 2008), but have struggled for acceptance (Popkin, 2009). Many educators have shared positive results, but the research on Physics First programs has been highly anecdotal, qualitative, and not far-reaching enough to establish its use beyond the context of a particular school environment (Neuschatz et al., 2008; O'Brien & Thompson, 2009; Pasero, 2003). This study provided the secondary science education community with a quantitative assessment of Physics First and the influence on math achievement. This quasi-experimental, quantitative study described and evaluated the influence of the PF-PCB program on SAT math test scores at a MRHS of Physics First (PF) students (completed the ninth-grade physics course and subsequent 10<sup>th</sup>- and 11<sup>th</sup>-grade courses) and non-PF students (not enrolled in ninth-grade science course but completed the subsequent 10<sup>th</sup>- and 11<sup>th</sup>-grade courses).

### **Significance of the Study**

Some educators have stated moving physics to the ninth grade corrects a century-old mistake when physics began to migrate to the upper grades. Though the majority of science teachers who teach in the traditional BCP sequence oppose such a change. Neuschatz et al. (2008) reported that 70% of teachers participating in a Physics First program responded with positive opinions about it and that 80% of physics teachers desired that all students should take the course by the end of high school. Regardless, the majority of educators and researchers responded they would like to see physics remain last in the sequence, so that it could remain a sophisticated math course precluding it from access by all levels of students (Neuschatz et al., 2008). This survey confirmed the common view that high school physics requires advanced topics in math like geometry, trigonometry, and calculus. Physics defined at this level of math is too challenging for ninth graders and therefore should be placed in the 12<sup>th</sup> grade (Neuschatz &

McFarling, 2003). Others have countered that because physics is a science course rather than a math course, it should utilize the tools of mathematics, not be driven by it. Wilt (2005) summarized this position claiming “mathematics and conceptual perspectives provide no sufficient reason not to offer physics as a first science course (and) no reliable reason exists to believe that the concepts are beyond those students' [ninth graders'] reach” (p. 351).

O'Brien and Thompson (2009) stated that while these arguments presented by Physics First advocates may seem logical, there is a scarcity of empirical data to help determine the extent to which a Physics First program actually benefits students. Many educators have reported success in teaching physics first, but these reports have been mostly anecdotal and lacking quantitative data.

Project ARISE reported their most significant finding in a 2001 study of Physics First schools was “that schools are not quantitatively documenting the degree of their success” (Pasero, 2003, p. 13). Neuschatz et al. (2008) found while 3% of public and 8% of private U.S. high schools have adopted Physics First, the “only information about Physics First is anecdotal” (p. 26). Glasser (2012) asserted “while the movement to an inverted curriculum has occurred in a number of schools, it could be accelerated if more data supported its effectiveness” (p. 54). In order to be considered a viable alternative to the traditionally ordered science course paradigm, the PCB curriculum needs to be investigated more thoroughly in a quantitative manner to ensure its scope of validity and reliability in all applicable environments. O'Brien and Thompson conclude that “until more empirical data are available, the academic value of a Physics First curriculum will be merely a matter of opinion” (p. 238). MRHS provided an



excellent opportunity to quantitatively evaluate student achievement in a PCB program and thus inform the Physics First debate.

### **Conceptual Framework: How Students Learn**

This study was situated in the historical context of secondary science education and emerging learning theory. The conceptual framework for this study was grounded in constructivism (Bransford & Brown, 2000; Bybee, 2009a, 2009b; Bybee et al., 2006; Donovan & Bransford, 2005, 2007). Donovan and Bransford (2005) applied modern learning theory, deeply rooted in constructivism, to science education. They illuminated the importance of addressing and appreciating the preconceptions and experiences of students. A constructivist approach optimizes the learners' prior knowledge and experiences, so as to build a stronger conceptual base over time by assimilating new concepts into the context already established within each individual. The idea is context over concept, application over memorization. Thus, this study predicted the sequence of the big understandings in science matters; learning more sophisticated concepts in science requires a foundation of more basic concepts. Thus, a coherent, sequential science curriculum beginning with physics, should optimize learning.

### **Research Question**

This study answered the following question: Do Physics First (PF) students in the Physics First program at Matteo Ricci High School (MRHS) have higher SAT math scores than their non-PF counterparts when controlling for prior math achievement, race/ethnicity, and SES?

### **Hypothesis**

PF students in the PF-PCB program at MRHS will have higher SAT math scores than their non-PF counterparts, while controlling for their prior math achievement, race/ethnicity, and SES.

### **Research Design and Methodology**

The site of investigation, MRHS, was an ethnically diverse, private, single-sex (all male), Jesuit Catholic high school in the western United States. The school is located in a large, highly diverse urban area. MRHS adopted a Physics First curriculum by inverting its traditional science curriculum sequence from BCP to PCB. In the fall of 2007, an algebra-based physics course was offered to all ninth-graders; chemistry was mandated for all 10<sup>th</sup>-graders; and life science courses were offered to 11<sup>th</sup>-graders (Biology, AP Biology, or AP Environmental Science).

Approximately two-thirds of students in the first two graduating classes (Cohorts 1 and 2) in the PF-PCB program enrolled in the ninth-grade physics course and were designated as the PF group in the study. The other one-third of each cohort chose not to take science in the ninth grade but took 10<sup>th</sup>-grade chemistry and 11<sup>th</sup>-grade biology: These students were designated as the non-PF group. After the ninth-grade year, each cohort (class year) of students continued through the science program by taking both 10<sup>th</sup>- (chemistry) and 11<sup>th</sup>-grade (life science) science together. PF and non-PF students were not separated after ninth grade.

The study considered math achievement and demographic data from MRHS for the first two cohorts ( $n = 571$ ) of the Physics First program. These data were analyzed and differences between Cohort 1 and Cohort 2 (the Class of 2011 and 2012, respectively) and between PF and non-PF were investigated. Math scores from the High School Placement Test (HSPT) and the SAT were used to determine math achievement. HSPT math scores determined prior math

achievement and SAT math scores determined math achievement after the PF-PCB program. Demographic data were used to determine differences in the race/ethnicity and SES of PF and non-PF groups. In addition to HSPT math scores, the race/ethnicity and SES data provided the opportunity to evaluate SAT math scores while controlling for these three variables. A statistical analysis of covariance (ANCOVA) was used to determine the influence of the PF-PCB program on SAT math scores while controlling for HSPT math scores, race/ethnicity, and SES.

### **Variables**

In the study, students in Cohort 1 and 2 were grouped based on their choice of ninth-grade science. The independent grouping variable (IV) was the PF-PCB program. Students that complete the PCB sequence were designated PF and those that did not take ninth-grade science and completed the chemistry and biology were designated non-PF. The dependent variable (DV) was math achievement, as defined by the SAT math test scores, reported after the PF-PCB program. HSPT math scores determined prior math achievement and were used to address the issue of self-selection in the study. Statistical methods (ANCOVA) were used to control for the influence of prior math achievement on SAT math scores. Race/ethnicity and SES were also factors of interest. On both the SAT and HSPT, students reported self-identifying data. Their choice of racial/ethnic identity and reported zip codes were used to establish race/ethnicity and SES for the study. Median income data for residential zip codes were used to establish SES. In addition to prior math achievement, the statistical analysis (ANCOVA) controlled for SAT math scores and SES. The ANCOVA determined whether SAT math scores differed significantly between PF and non-PF students in Cohort 1 and 2 at MRHS while controlling for HSPT math scores, race/ethnicity, and SES.

## **Limitations and Assumptions**

There were limitations and assumptions in this quantitative study of Physics First at MRHS. First, this study analyzed the performance of two classes (2010 & 2011) of PF and non-PF students at a single school over the first five years of a new program. MRHS was a college preparatory, single sex, private high school with a record of high student achievement; it has its own unique culture, climate, and conditions. Thus, the ability to generalize the results of this study may be limited. Second, the study was non-random, non-experimental, and, while causality cannot be deduced, it may be inferred. Third, student achievement is complex and the conditions that promote student achievement are nuanced. While MRHS provided a great opportunity to compare student achievement in a PF-PCB program, there are many other factors at the school which play a significant role in the results. For example, teaching enthusiasm, engagement, and effort were high during implementation of the PF-PCB program, and this may have affected student learning. Fourth, incoming students and their parents chose whether or not to take science during the ninth grade. This results in the susceptibility of self-selection that the study addressed by controlling for math achievement, race/ethnicity, and SES. Higher achieving students, or students with greater interest in learning science and mathematics, may achieve higher scores. The issue of higher achieving math students self-selecting ninth-grade physics was addressed in the methods and controlled for in the analysis. Fifth, MRHS is a single-sex (all male) high school. It is assumed that all types of high school students could be more successful in a PF-PCB program, but this study was limited to boys. Sixth, there is natural variability in teaching methods, especially when adopting an inquiry approach. Seventh, PF students have three years and non-PF students two years of science before taking this Math SAT. There could

be an advantage to having more exposure to science. Lastly, the researcher was both a teacher and science department chair at MRHS during the implementation of the program.

As with most educational studies, a lack of control in this study and many other variables may have influenced the results. Ex post facto data were used to determine whether differences existed between two groups of students in a causal-comparative manner based on whether students took physics as ninth-graders (PF) or no science in the ninth grade (non-PF). But other changes occurred on MRHS's campus at that time. The school had recently completed a new, state-of-the-art science building. A new technology director purchased and distributed computers and data-logging equipment to science laboratories. New science teachers were hired during that time and the consistency of the program varied from teacher to teacher and year-to-year. While there were no substantial changes to the math curriculum, the new technology-rich, inquiry-based methods of instruction by highly motivated science teachers may have influenced learning in a substantial way. All these factors may have contributed to differences in student achievement described in the results.

It was assumed that a correlation existed between math and science achievement in the study. No standardized test was used to measure the pre- and post-achievement of MRHS students in science, but it was assumed by the researcher that if they were doing well in math then they were also doing well in science. Physics First lends itself to the reinforcement of mathematical skills early in a high school science program. Glasser (2012) found "a strong association between physics in the ninth grade and improved test scores on the mathematics portion of the PSATs for [PF] students" (p. 54).

It was assumed that the zip code data could be used as a good measure of SES. Household income data were not available for students at MRHS and student zip codes were used to report median incomes to determine SES (ZipAtlas, 2012). While each method has limitations, it proved sufficient to determine whether the SES differed significantly in PF and non-PF groups.

### **Delimitations**

The boundaries that existed for this study included the school site (MRHS), the students, and the instruments (tests). The standardized tests (HSPT and SAT) were the measures of student achievement in mathematics. It was assumed by the researcher that these exams provide an accurate and convenient way to standardize measures and determine achievement.

### **Definition of Terms**

The following definitions provided uniformity and are used in this research study:

- Civic scientific literacy (CSL): refers to the ability to read and understand the science found in a typical New York Times article (Tuesdays), or to comprehend the scientific explanations shown on a NOVA television show. A scientifically literate citizen needs to possess: (a) a basic vocabulary of scientific terms and constructs; and (b) a general understanding of the nature of science (J. D. Miller, 1998). A 21<sup>st</sup>-century society requires a citizenry that is knowledgeable about scientific and technological issues for the democratic process to function properly. Basic scientific literacy informs the decision-making process and promotes better strategies to address challenges. (J. D. Miller, 2002).
- Curriculum: a designed sequence of study to learn knowledge, skills, and understandings of a particular discipline.

- Inquiry-based instruction: instructional method of teaching in which a teacher creates learning experiences and guides the inquiry process by addressing preconceptions, formulating questions, setting up a problem, investigating, sharing results, discussing and reflecting. Students arrive in the classroom with conceptions, skills, and abilities. A meaningful context promotes the conditions to further develop concepts, skills, and abilities. (Bybee et al., 2006).
- Instruction: the teaching methods including, but not limited to, planning, creating, and guiding learning experiences for students.
- Physics First (PF-PCB): (a) the independent grouping variable of the study, students who participated fully in the PF-PCB program by enrolling in the ninth-grade physics course were designated PF; (b) a high school science program that teaches the traditional science disciplines in the following order—physics, chemistry, and biology (PCB).
- Scientific Literacy: includes the ability to apply scientific understanding to life situations involving science (Bybee, McCrae, & Laurie, 2009); using scientific knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, and to draw evidence-based conclusions about science-related issues; willingness to engage in science-related issues, and with the ideas of science, as a constructive, concerned, and reflective citizen (Bybee et al., 2009). The American Association of Physics Teachers (AAPT) predicted that PF-PCB would promote greater scientific literacy among students (AAPT, 2002).

- Traditionally taught physics: didactic instruction, grounded in lecture, demonstration, introduction of laws and formulas, math problems that illustrate the concept, and lab activities used to verify the material.

### **Summary**

The state of secondary science education in the United States is in a state of urgency. Reforming education in the light of contemporary learning theory and best practices is paramount. Physics First (PF-PCB) is a curriculum that should be evaluated quantitatively and, if shown to be effective, considered as a replacement for the traditional, predominant BCP curriculum. This study of PF-PCB at MRHS offered another positive step toward evaluating and considering alternative, modern, secondary science curricular models.

In Chapter 1 the background, problem, significance, and conceptual framework of the research have been presented. Chapter 2 reviews the history of science education and provides current research about the topic. Chapter 3 describes the methodology and presentation of the data. Chapter 4 provides the analysis of the data and results of the research. Chapter 5 discusses the significance of the findings and offers direction for future research.



## CHAPTER 2

### REVIEW OF THE LITERATURE

#### Introduction

This chapter presents the review of the literature on secondary science education in the United States and an alternative program, Physics First (PF-PCB). High school curricula, particularly the sequence of courses, were reviewed in light of the history of science education. This historical context illuminated the nature of the problem presented in this study that the predominant curricular order, biology–chemistry–physics (BCP), found in most high schools today, may need modernization to improve science, technology, engineering, and mathematics (STEM) literacy and access to science.

Leon Lederman, winner of the Nobel Prize in physics, championed revolutionizing secondary science education by “putting physics first” (Lederman, 1998, 2001, 2005). He promoted the idea that high school science should begin with an introductory, algebra-based, physics course to provide a foundation for other courses. As a result Lederman is often credited with coining the term “Physics First” (PF) to describe the variety of secondary science programs that offer physics as a first-year course. Justification for the PF-PCB program is described here and the growth of the Physics First movement detailed.

History shows that physics was revered as the foundation of the other sciences and that curricular order of physics–chemistry–biology (PCB), also known by many as Physics First, was considered logical (Sheppard & Robbins, 2002, 2003, 2005, 2009). Despite this reasoning, by the middle of the 20<sup>th</sup> century, most high schools pushed physics to the final spot in the curricular order, offering it in 11<sup>th</sup> and 12<sup>th</sup> grades. Today, schools have inherited a “physics last” (BCP)

curriculum that is now associated with sophisticated math, and as a result, remains elusive to most students (Neuschatz, McFarling, & White, 2008; Neuschatz & McFarling, 2003).

The growth of scientific knowledge over the last century, particularly in biology and biotechnology, has grown, thus the curriculum must grow (National Research Council [NRC], 2007). “Science education must change—and change soon. The amount of technical information available to humanity doubles every few years, and this information eventually makes its way into the high school science curriculum” (Wilt, 2005, p. 360). This growth in science content requires educators to reconsider *what* is taught in science and *when* is it best to teach it. Physics First proponents argue that proper understanding of modern biology requires knowledge of chemistry, and that chemistry is better understood with a foundation in physics.

The reasoning for an improved, coherent high school science sequence is grounded in constructivism (Bransford, Brown, & Cocking, 2000). If students learn best by connecting new knowledge upon existing conceptions then the order in which students learn the major concepts in science matters: determining an optimal curricular order is situated in constructivism. Contemporary constructivism, as described in *How Students Learn* (Donovan & Bransford, 2005), offers an explanation for improved student learning when concepts are presented in a logical sequence (PCB). Higher student achievement in 11<sup>th</sup>- and 12<sup>th</sup>-grade science and mathematics by Physics First students may indicate a better edifice of scientific and mathematical understanding. This study determined that students in a Physics First program at Matteo Ricci High School (MRHS) had significantly different SAT math scores when controlling for prior math achievement, race/ethnicity, and SES.

The instruments to measure student achievement in mathematics and the variables are presented and reviewed in this study. The PF-PCB program is the independent grouping variable and the dependent variable is student achievement in mathematics based on standardized math scores. PF students are those that completed the PF-PCB program; they had ninth-grade physics and completed three years of science by end of 11<sup>th</sup>-grade. Non-PF students took no science in the ninth-grade and completed chemistry and biology (or equivalent life science) by end of 11<sup>th</sup>-grade. The SAT is typically taken after the 11<sup>th</sup>-grade. The math section of the SAT served as the standardized measure of math achievement for the study. These measures were used to describe and compare the SAT math scores of PF and non-PF students in the first two cohorts of MRHS's PF-PCB program.

### **History of Secondary Science Education in the United States**

Is the United States teaching high school science backwards? If so, how did it get this way? The history of secondary science education was reviewed to set the context for current challenges. It was important to understand the origins of the predominant curricular order: biology–chemistry–physics (BCP). Whether by happenstance or design, history shows that curriculum and instruction evolved in a way that may not be optimal for student learning in the 21<sup>st</sup> century and may exclude many. In addition, the scientific enterprise may be advancing faster than education can adapt. Given the needs to include new scientific knowledge and to optimize student learning, science education reformers must confront the predominant curricular order lest American students be prepared for the wrong century.

## **The Beginnings of Science Education**

In 1892, the National Education Association (NEA) organized the Committee of Ten (CoT) to propose a standardized course of study to better prepare American high school students for college. Interestingly, the CoT proposed something very similar to Physics First, yet it is often wrongly accused of initiating the BCP sequence (Sheppard & Robbins, 2002, 2003, 2009). The CoT was separated into subcommittees and tasked to address the different disciplines and academic subjects. Three science committees (Physical Science, Natural History, and Geography) were composed of distinguished educators and scientists of that time. They addressed what should be taught (curriculum), how much time should be allocated, and how it should be taught (instruction) and assessed (Sheppard & Robbins, 2002, 2005). One of the three science committees, the Physical Science committee, recommended a chemistry and physics course for college admission, with the physics course being taught in the final year of high school (CP). The Physical Science subcommittee admitted the order was illogical in terms of content, but asserted that delaying physics to the upper grades gave students the chance to accumulate the most mathematical knowledge (NEA, 1893 as cited in Sheppard, 2002). One dissenting vote on that subcommittee suggested that chemistry was more abstract than physics and it was not logical for chemistry to precede physics. The other two subcommittees were in agreement with the rationale of the dissenting voter; they suggested that physics be placed before chemistry (PC) (NEA, 1893 as cited in Sheppard & Robbins, 2002). The full CoT accepted this view and recommended to the NEA that physics be placed before chemistry (PC). There was no mention of biology since this course did not exist as it does now. Putting the physics course first

was logical and provided the opportunity for more students to take the course, given many did not complete high school at that time (Sheppard & Robbins, 2003, 2005).

In 1986 the CoT's recommendations were altered when the NEA created a new committee, the Committee on College Entrance Requirements (CCER) to plan the implementation of the high school curriculum. Unfortunately for the proponents of science education, the CCER "took a less positive view of the value of science" (DeBoer, 2010, p. 283). They recommended a one-year science requirement for college admission instead of the four proposed by the CoT. The NEA's decision to adopt the CCER's recommendation reflected a desire to emphasize the study of the classics; as such one year of science was required. As a result physics and chemistry courses were pushed to the higher grades (Sheppard & Robbins, 2003, 2006) and the debate concerning whether physics should precede chemistry continued.

Alexander Smith, a notable chemist working in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries, played an important role in the debate; he promoted putting chemistry last (cited in Sheppard & Robbins, 2006). For Smith the order was important: "physics must come first" (quoted in Sheppard & Robbins, 2006, p. 1617). Smith argued that physics was foundational to chemistry and that the amount of mathematics taught at this time (algebra and geometry) was sufficient to succeed in physics. In addition, Smith was like other professors who coveted teaching the 12<sup>th</sup> grade; it was considered prestigious. The top students were in the year closest to college and teachers believed they could cover the most material and get the best work out of them (Sheppard & Robbins, 2006). Thus, Smith reasoned that physics should precede chemistry because chemistry was the elite course for the eldest students; it was more abstract and complex.

Physics, the more concrete science, is foundational to the more abstract science, chemistry, thus should precede it.

### **The Birth of Biology—the Fall of Physics**

In the early 20<sup>th</sup> century, high school science became a requirement. At the same time, course offerings, as well as the number of students taking science, began to grow. In 1890, approximately 200,000 students were enrolled in high school in the US; by 1900, enrollment was more than 500,000; and by 1920, 2 million students were enrolled (NCES, DATE, as cited in Sheppard & Robbins, 2005). Botany, zoology, and physiology were combined into one single discipline: biology. In addition to biology, general science emerged and become popular. Due to their simple, descriptive nature, both biology and general science were placed in the early years of high school (ninth- and 10<sup>th</sup>-grade). Even with the growth in course offerings and the number of students in high school, most schools at this time still offered physics before chemistry (Sheppard & Robbins, 2009).

By the 1930s, biology courses had become firmly established early in the science sequence and more students took biology courses than physics and chemistry courses combined (Sheppard & Robbins, 2003, Fig. 2, p. 423). Meanwhile the order of physics and chemistry began to flip, with physics becoming the terminal science and chemistry the central science. By 1948, more than 80% of physics classes were in the 12<sup>th</sup> grade (Sheppard & Robbins, 2003). Interestingly, “with the exception of the Physical Science Subcommittee of the CoT, by World War II no committee had actually recommended that chemistry be placed before physics” (Sheppard & Robbins, 2005, p. 564). Despite the widely expressed view that physics was foundational to chemistry, the PC sequence slowly evolved into the BCP sequence (Sheppard &

Robbins, 2006). The rise of biology as the introductory science and the movement of physics as the terminal science resulted in a decline in physics enrollment: introductory biology courses essentially replaced introductory physics courses. Thus students in a BCP curriculum were less likely to enroll in a third year of science, such as 12<sup>th</sup>-grade physics, after meeting their required one or two years of science in the 10<sup>th</sup>- and 11<sup>th</sup>-grades. “By the late 1940s, most students learned about science through the general science course and one other disciplinary course, usually biology” (DeBoer, 2010, p. 288). Biology rose, chemistry remained the same, and physics enrollment dropped precipitously over the first half of the 20<sup>th</sup> century.

### **Global Change and the Advancement of Science**

In the second half of the 20<sup>th</sup> century, the importance of science education shifted in the United States. In 1957 the space race began with the launch of *Sputnik*. This provoked the U.S. government to address the state of science education with the fear that it was losing its place as a global leader in science and engineering. Using national security arguments, the government called on the education community to increase the pipeline of scientists and engineers and to grow a strong, talented and innovative workforce for military and economic security. This represented a change in the importance and goal of science education; it became a matter of national security and competitiveness rather than personal and societal usefulness (DeBoer, 2010). This call to develop a scientifically trained workforce led to many studies and reports in the following decades that, depending on the group publishing the report, emphasized updating content knowledge, improving in teaching strategies, recruiting high-quality science teachers, and creating a scientifically literate citizenry.

At its first meeting in 1971, the National Science Teachers Association (NSTA) made “scientific literacy” the most important goal of science education. This term described what people needed to know to be better citizens and to create a better society. In the 1980s, F. James Rutherford and the American Association for the Advancement of Science (AAAS) (1993) began a long-term effort to reform science education and promote science literacy for all called “Project 2061” (named for the year in which Haley’s comet returns). The work began with the publication *Science for All Americans* (AAAS, 1990) that recommended a minimum of three years of an interdisciplinary science curriculum coordinated with mathematics so that a student’s scientific literacy could be properly developed (Bardeen & Lederman, 1998). Project 2061 and *Science for All Americans* provided the vision and the impetus to bring science literacy to all (DeBoer, 2010). Soon thereafter, standards in science education were published. The AAAS created *Benchmarks in Science Literacy* (1993) and the National Research Council (NRC) published *National Science Education Standards* (NSES) (NRC, 1996) to determine what all students at specific grade levels should know and be able to do in order to achieve the goal: science literacy by the end of high school.

In spite of the early calls for science education reform, whether for reasons of national security or a scientifically literate citizenry, the number of high school students taking physics fell to its lowest levels in the 1970s with only one in five students taking the course (Neuschatz & McFarling, 2003). Even more alarming was the number of women (15%), African American (10%), and Latino/Hispanic (10%) students enrolled in physics in the two decades that followed (Neuschatz & McFarling, 2003). For economically disadvantaged or marginalized students, these numbers may be inflated because these students often had a higher risk of dropping out of school



and would lack the opportunity to take physics given that 99% of all U.S. high schools followed the BCP sequence by 2003 (Sheppard & Robbins, 2003).

The economic drive to compete internationally, to improve the quality of science education, and to increase the number of trained scientists continued as the 20<sup>th</sup> century came to a close. By the early 1990s “more than 300 reports admonished those within the education system to reform science education” (DeBoer, 2010). *A Nation at Risk* (NCEE, 1983) warned of mediocrity in America and summoned the education system to raise the level of competence of its students, especially in science and mathematics, in order to compete economically in a more globalized, knowledge-based economy. More recently, the Trends in International Math and Science Studies (TIMSS) (Martin et al., 2008; Martin et al. 2012; Smith et al., 2000), the Program for International Student Assessment (PISA) (OECD, 2006, 2009) and the National Assessment of Educational Progress (NAEP) (NCES, 2011) have confirmed that the American students are falling behind their international counterparts. Many of these reports suggest that improvements in science education are needed to compete economically in a global, technology- and knowledge-based world, which begs the question: Is the primary goal of science education in the U.S. to provide more, better trained scientists and engineers to maintain global competitiveness?

According to Bybee (1995) the science curriculum reforms in 1990s differed from previous ones. With national benchmarks serving as a guide, all levels of science education were addressed beginning at elementary levels. The NSES and frameworks were interpreted and implemented at the state level. These standards of what students should know (content) and what they should be able to do (skills) were published and ultimately assessed by states, per the

federal mandate of 2001, *No Child Left Behind* (NCLB). The 1990s marked a new type of education reform and changes in science education were apparent; more students were taking science and traditional gaps in science began to close.

Perhaps in response to *A Nation at Risk* (NCEE, 1983) or to the many reports that followed, enrollment in the sciences, particularly in physics and chemistry courses, began to increase. By 1992 many states increased their graduation requirements from the CCER's one-year recommendation in 1896 to two or three years of science. The percentage of students taking chemistry nearly doubled (Sheppard & Robbins, 2005). By 2005, one-third of high school 12<sup>th</sup>-graders had taken physics before graduating compared to one in five in the 1970s (Neuschatz & McFarling, 2003). This represents a near doubling of high school students taking physics within fifteen years; from 620,000 students in 1990 to 1.1million in 2005 (Neuschatz, McFarling, & White, 2008). In addition, enrollment of female students and underrepresented minorities increased rapidly. From 1990 to 2005 enrollment increased for both African American and Hispanic/Latino students from 10%, to 23% and 24%, respectively (Neuschatz et al., 2008). Neuschatz, McFarling, and White (2008) reported that “no longer is high school physics predominantly a preserve of white males” (p. 2). With an increase in science graduation requirements, the growth in physics enrollment could be explained by the significant expansion of honors, Advanced Placement (AP), and conceptual physics courses, with some modest gains in growth due to programs like Physics First (Hehn & Neuschatz, 2006; Neuschatz et al., 2008; Neuschatz & McFarling, 2003).

## **The Physics First Movement**

The evolution of science education over the last 100 years in the U.S. reveals the nature of the inherited high school science curriculum and the need for reform. As of 2003, 99% of all U.S. high schools were following the BCP sequence (Sheppard & Robbins, 2003). While the increase in science enrollment since the 1970s, particularly in physics, is encouraging, two-thirds of 12<sup>th</sup>-graders still graduate from high school without taking physics (Brinton, 2007). In 1998 Leon Lederman organized the American Renaissance in Science Education (ARISE) and stressed the importance of evaluating science curriculum and instruction. ARISE proposed that the high school science sequence begin with physics in the ninth grade, followed by chemistry in the 10<sup>th</sup> grade, then biology in the 11<sup>th</sup> grade (PCB), the most common type of PF program (PF-PCB). The history of science education shows that conceptually PCB was considered the most logical curricular sequence. Many agree, but the debate may have settled on the level of mathematics needed to do physics, a discussion that began over 100 years ago with the CoT. But there may be something new to consider in the debate: the recent acceleration of growth in biological knowledge.

## **The Biological Revolution**

A vast new direction in the biological sciences was forged in the second half of the 20<sup>th</sup> century. In 1953, Francis Crick and James Watson revealed the structure of deoxyribonucleic acid (DNA) and in 2000, Craig Venter and Francis Collins announced the end of the race to sequence the human genome. That day in the summer of 2000, marked a new revolution in science: “Biology 2.0” (Carr, 2010) and a new race began to decipher the meaning of the newly-coded DNA. The biology practiced in the year 2000 was much different than the biology course

typically found in high schools. It was no longer an amalgamation of the descriptive sciences - botany, zoology, and physiology - of the 1930s (Wilt, 2005). Biology has grown most notably in the realms of molecular and cellular biology, such as microbiology. Modern biology is highly molecular in nature and teachers are struggling to incorporate and properly teach the large amount of new, molecular material (Wilt, 2005). The typical biology course in the 21<sup>st</sup> century covers DNA, proteins, and the inner workings of the cell. This is evidenced in high school texts in which the number of pages devoted to microbiology is growing and nearly one-third of state biology assessments contain biochemistry (Haber-Schaim, 1984). Starting with Watson and Crick (1953) and propelled by Craig Venter's (Venter et al., 2001) and Francis Collins's (Lander et al., 2001) joint release of public and private advancements in human genome research, the late 21<sup>st</sup> century may eventually be known as the biological revolution, or Biology 2.0, and one might ask: What is the best placement for a modern biology course in a 21<sup>st</sup> century high school curriculum?

Clearly the high school biology course of the early 20<sup>th</sup> century should not be the same as the biology course of the early 21<sup>st</sup> century (Sheppard, 2007, 2009). Given advances in molecular biology (i.e., genetics and biochemistry) the placement of this course in the secondary school curriculum should be examined (Sheppard, 2002, 2003). The PCB sequence can better prepare students for the molecular nature of modern biology than "biology first" sequence (BCP). A PCB sequence provides students the opportunity to construct their scientific knowledge and understandings in a logical, coherent manner, and prepare them best to learn, 21<sup>st</sup> century, modern biology. Evidence for this can be found in the course catalogues of universities.

Understanding modern biology requires understanding the behavior of molecules and atoms—essentially chemistry—which is in turn grounded in physics (Cavanagh, 2006). Interestingly, the reverse is not true (Wilt, 2005): an understanding of physics neither requires chemistry nor biology as evidenced by undergraduate programs in physics across the nation. Biology majors are typically required to take one year of introductory physics and two years of chemistry (general and organic chemistry); however, physics majors are not required to take introductory biology and chemistry. Thus, in the 21<sup>st</sup> century high school curriculum, the placement of biology as a first course by the majority of schools, 96% (Neuschatz et al., 2008) to 99% (Sheppard & Robbins, 2003), may be backwards.

Since the 1990s, support for Physics First in secondary science education has grown. Science education researchers have recommended that a strong three-year science curriculum should begin with physics offered in the ninth grade (Bardeen & Lederman, 1998; Eisenkraft, 2010; Hake, 2002; Hehn & Neuschatz, 2006; Lederman, 1998, 2001, 2005; Neuschatz et al., 2008; Neuschatz & McFarling, 2003; Wilt, 2005). The Association of Physics Teachers (AAPT) demonstrated support for Physics First programs (AAPT, 2002, 2007), highlighting the increase in the number of students having access to the course (Eisenkraft, 2010). The AAPT went further and recommended the development of age-appropriate curricula and more effective pedagogy for a ninth-grade physics course (AAPT, 2002). The Biological Science Curriculum Study (BSCS) group examined and promoted the reorganization of the high school curriculum to PF-PCB in their report *The Cornerstone-to-Capstone Approach: Creating Coherence in High School Science* (BSCS, 2006). While influential science researchers and organizations have demonstrated support for PF-PCB programs, opposition remains.

## Opposition to Physics First

Surveys show that the majority of science teachers are opposed to the PF curricula (Neuschatz & McFarling, 2003). Despite the support and justification for Physics First, many educators and researchers still define physics as a sophisticated mathematical course that is best placed in the 12<sup>th</sup> grade (Mervis, 1998; Neuschatz & McFarling, 2003). Proponents of PF counter that the bulk of physics does not require higher-order math (i.e., trigonometry and calculus) to understand the concepts, but most concepts in physics can be effectively described by basic algebra, a course completed by most incoming ninth-graders in the U.S (Wilt, 2005). Glasser (2012) stated that “physics does not need to make use of trigonometry or calculus and truly only needs to use algebra. If the sequence is not inverted, students may not use their algebra skills... two or three years after their first algebra course” (p. 53). Defining physics as a sophisticated mathematics course restricts enrollment to those who are more mathematically inclined and have had access to high-quality math instruction. In addition, schools view the challenges to implementing Physics First as insurmountable: alignment of states exams, resistance of parents and teachers (Taylor, 2005), the preference of the BCP sequence, transfer students, the need for more equipment and labs, and the difficulties in hiring scarce physics teachers (Pasero, 2003). Similar to Alexander Smith’s argument in the 1900s that chemistry was elite, complex, and should precede the first year of college, science teachers today argue that physics should be mathematically sophisticated and college-like. Sheppard and Robbins (2003) rebut this view, stating that “by mimicking college physics, the subject became inaccessible... rather than being reformed” (p. 422). Re-defining physics as a science course, rather than as a sophisticated,

applied mathematics course, is an important component to the Physics First movement and appears to be growing.

### **The Rise of Physics First**

The adoption and implementation of Physics First has been slowly gaining ground and the number and types of students taking physics is growing. Neuschatz, McFarling, and White (2008) estimated “that 4% of all U.S. high schools – 3% of all public and 8% of all private schools – had implemented some variant of Physics First by 2005” (p. 27) with “5% of all students in the nation (4% in public schools and 12% in private schools) enrolled in a school with Physics First curriculum” (p. 28). In these PF schools, 73% of student take physics by graduation, essentially doubling the national average of BCP schools (Neuschatz et al., 2008). Teachers were also surveyed. Of those participating in a PF curriculum, over 70% had positive opinions on the curriculum (Neuschatz et al., 2008). Neuschatz et al. (2008) also noted that “no longer is high school physics predominantly a preserve of white males... females students have reached near parity... [and] underrepresented minorities have made great strides... towards closing the historical gap in enrollment” (p. iii). Physics First programs grew in number and in the types of students taking the course.

A study by Pasero (2003) reported that student attitudes improved at Physics First schools in the U.S. He surveyed 58 schools, mostly private in the northeast and western parts of the U.S. and found that Physics First programs had increased motivation towards physics. Students commented on connection of ideas, e.g., energy and structure of the atom, through the curriculum. Twelfth-graders felt that the curriculum prepared them well for subsequent courses.

Chemistry and biology teachers appreciated the base of knowledge their students possessed coming in to their courses (Pasero, 2003).

Glasser (2012) found that ninth-grade physics led to higher student achievement in mathematics at Germantown High School in Philadelphia. He used student pre- and post-scores on standardized mathematics tests and compared student scores in the traditional BCP to those in the newly inverted PCB sequence. Using the mathematics section of the PSAT as the post-score, Glasser found that students who took the ninth-grade physics significantly outperformed students that took the ninth-grade biology course where no pre-existing difference existed. Thus, “placing physics in the ninth grade coincided with an observed improvement in students’ mean performance on the math section of the PSAT” (p. 54).

Ewald, Hickman, Hickman, and Myers (2005) opined that simply using algebra skills earlier would explain higher achievement in math. Extending this thinking Goodman and Etkina (2008) urged that new Physics First programs “teach a mathematically rigorous ninth-grade physics course based on algebra alone, avoiding trigonometry” (p. 222). This would incorporate the arguments for both the opponents and proponents of physics in the ninth grade: make it mathematically rigorous and age-appropriate.

Studies like this one have responded to Project ARISE’s admonition that “[Physics First] schools are not quantitatively documenting the degree of their success” (Pasero, 2003, p. 13).

Pasero (2003) continues:

Information such as standardized test scores (whether on state-mandated tests or on tests such as the ACT and SAT II), enrollment in advanced science courses in high school, numbers of students going on to major in science in college, or any other relevant data would be invaluable, not only for studies such as this, but also for the schools themselves to be able to justify what they are doing and identify areas in which they can improve. (p. 13)



Marge Bardeen, a leading science education from the Fermi lab, was quoted:

We have anecdotal reports that more students take more science with [Physics First]... Interviewees had numerous anecdotes to support their efforts, but most of their schools had collected nonnumerical data for evaluative purposes... Some schools are collecting data but do not have enough to draw any conclusions yet. Unfortunately, in general, when schools and districts choose to make this change, they do not do it as an experiment. They do not necessarily have baseline data so that they cannot document the change with test scores, enrollment figures, etc. And for the most part, they don't see the need to do so for their own purposes. Since schools do not study their curricula changes as controlled experiments, it will be hard to quantify the success of the physics-first curriculum. (Pattanayak, 2003, p. 2)

This study responded to the call for quantitative studies of Physics First programs. It used standardized test scores in mathematics from the first two cohorts of students to graduate from MRHS's new PF-PCB program. SAT math scores of PF and non-PF students were compared. PF students were those that completed the PF-PCB program by taking ninth-grade physics, while non-PF students were those that did not take the ninth-grade physics course, but completed chemistry and biology before taking the SAT. This quantitative research contributes to the body of research need to evaluate the effectiveness of a PF programs.

### **Theoretical framework**

If students learn best when they are building their knowledge upon a network of prior knowledge, then the order in which students learn the major concepts in science and mathematics matters. The theoretical framework for this study is grounded in constructivism.

### **Student Learning**

Based on the foundation of work by Piaget (1963) and Vygotsky (1978), constructivists generally believe that knowledge is constructed in the mind and through social interaction.

Current research about how students learn science is reflective of the works of Piaget and Vygotsky (Bransford & Brown, 2000; Bybee, 2009; Donovan & Bransford, 2005; Gess-Newsome, Luft, & Bell, 2009). Students construct their knowledge through reorganization, accommodation, and assimilation of the new understandings to the prior conceptions (Wadsworth, 1996). New knowledge and conceptual understandings are best acquired by confronting prior knowledge and conceptions. The social interaction and attempt to resolve the cognitive conflict stimulates intellectual development in the mind of the student.

The review of the history of science education in the United States demonstrated that the predominant high school curricular order (BCP) was not guided by how students construct conceptual knowledge. Rather, the descriptive nature of mid-century biology and the determination that physics required sophisticated mathematics prescribed the order. If student learning is the goal, then the high school science curricular order should be evaluated in light of constructivism and intentionally aligned in the same way that language (e.g. French I, French II, and French III) and mathematics (e.g. Pre-Algebra, Algebra I, Algebra II) are aligned to build knowledge and skills. Physics First (PF-PCB) programs are aligned in a conceptual way by putting physics first, biology last, and chemistry in the middle.

Bardeen and Lederman (1998) argued that a PF-PCB curriculum creates coherence and the “objective is to build knowledge of science... following the hierarchical nature of science as it has unfolded over the past century” (p. 178). A sound understanding of chemistry requires knowledge of physics, and biology requires chemistry. In the traditional BCP sequence, biology and chemistry teachers and textbooks often refer to concepts that have been neither properly

introduced nor learned. They would not have to do this if physics were taught first (Bardeen & Lederman, 1998).

Constructivist theory was used in this study to explain the need for modernizing science education practices and sequencing of science concepts to improve student learning. If a PF-PCB curriculum shows higher math achievement, then constructivism offers an explanation for improved, deeper understandings of science and mathematics concepts.

### **Lack of Conceptual Understanding**

The majority of students in the United States leave high school unprepared to do college-level math and science. In 2012 only 31% of the 1.67 million ACT-tested high school graduates met college readiness benchmarks in science and 46% met such benchmarks in mathematics (ACT, 2013). College professors have long expressed disappointment in the lack of conceptual understanding of physics demonstrated by incoming college students, especially those that took physics in high school (Halloun & Hestenes, 1985a). In order to investigate the problem, studies were done and new instruments created to measure students' conceptual understandings of core concepts in physics (Halloun & Hestenes, 1985a, 1985b; Hestenes & Halloun, 1995). Hestenes, Wells, & Swackhamer (1992) created the Force Concept Inventory (FCI) to assess understandings and beliefs about common force and motion problems, i.e., Newtonian mechanics. The assessment indicated that students did not comprehend the most basic Newtonian concepts after taking a year of high school physics. It appeared that rote memorization and math-laden, formulaic teaching dominated the course (Hestenes & Halloun, 1995; Hestenes et al., 1992). Physics became the second mathematics class of the day and students lacked conceptual understanding of physical phenomena. For example, 80% students

were able to state Newton's 3<sup>rd</sup> Law while the FCI data showed less than 15% of them fully understood it (Hestenes, 1998). The data suggested that traditional instruction, i.e. lecture, induces only a small change in understandings and beliefs about physics; thus, instruction needs to be addressed in order to improve understanding in physics (Halloun & Hestenes, 1985).

### **Importance of Teaching Practices**

In 2000, the seminal work on the science of learning: *How People Learn: Brain, Mind, Experience and School* (Bransford, Brown, & Cocking, 2000) addressed the problems with the traditional learning and communicated findings that could impact classrooms. Donovan and Bransford extended the findings described in *How People Learn* (Bransford et al., 2000) and gave specific science examples in *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005). Both books described the need to move from a traditional, teacher-centered, didactic, lecture-driven style of instruction to a new, student-centered, inquiry-, and experience-driven style. The research found that students did not replace their misconceptions unless they explicitly addressed their pre-conceptions, testing their ideas in labs or activities, reflecting on these experiences, and resolving their ideas by constructing new understandings. After this, the teacher could step in and introduce the theory, law, or formula. Essentially things were to be taught in reverse: the activity came before introducing the concept, not the other way around, i.e. laboratory activities that verify the concept first presented in lecture.

*Reforming Science Education* (Gess-Newsome, Luft, & Bell, 2009) and *Learning Science and the Science of Learning* (Bybee, 2002) corroborated these main points. Gess-Newsome et al. (2009) offered advice on how to change teaching so that students can achieve scientific literacy and be better prepared to work and live in the 21<sup>st</sup> century. Bybee (2002) shared stories from

science classrooms across the nation that modernized their science education practices. He created a model based on constructivist theory to describe the important components of science education: engaging, exploring, explaining, elaborating, and evaluating (The 5E Model).

### **Importance of Leadership and Empowerment of Teachers**

Empowerment of science teachers with curriculum, instruction, and assessment decision-making are key components to an adaptable science program. Collaboratively teachers and administrators are obligated to meet the challenges of advancing STEM education. With shared power schools can more readily discard outdated materials, curriculum, and instructional methods and take ownership of new ones. A unified science department can utilize that same line of inquiry and practices they teach their students; they should continually research, test, and refine curriculum, methods of teaching, and assessments. They should change *what* they teach (core curriculum), *how* they teach it (instruction), and *when* (sequence) it should be taught, meanwhile addressing the students' underlying question, "*why* learn it?" (relevance). Teachers should address their beliefs about how student learn science and discuss what should be taught, the nature of learning, how teachers should teach, and how learners should be assessed (Cullen, Harris, & Hill, 2012).

Small school districts and private schools may be positioned better to address beliefs about learning, share power, and respond to advances in STEM education. For example, Matteo Ricci High School (MRHS), a private, independent Catholic school on the West Coast with 1200 students has 12 science department members with a turnover rate less than 10%. Over time the stable community of science teachers has developed similar beliefs on teaching and learning. This resulted from shared leadership that empowered teachers and fostered strong collaboration

and professionalism. The science faculty at MRHS was empowered with choosing and implementing a new science program. They dedicated time on weekends and during the summer to review the science education literature, to attend regional and national conferences (California Science Teachers Association & NSTA), and to consult with science education professors. Common goals were set, student learning became the priority, and the science teachers at MRHS began to design a program with the “end in mind” (Wiggins & McTighe, 2005).

### **Summary**

There has been a revolution in science over the last century, but there has not been a corresponding revolution in science education. Students are living in a rapidly-paced, biological and innovation revolution, yet our high schools maintain fidelity to 20<sup>th</sup>-century curricula and instruction. Compelling reasons exist to change high school science education. No conceptually sound, student-centered reason exists for the current science sequence of biology – chemistry - physics (BCP). The current sequence simply evolved, and students in the U.S. have inherited a relic of the early 20<sup>th</sup> century. This artifact of education has made mathematics the obstacle for taking the most foundational science, physics. The relegation of physics to 12<sup>th</sup> grade has yielded a primarily, White, male, mathematically elite course that impresses college admission offices, but not college physics professors. There is strong anecdotal evidence for changing the science sequence from BCP to PCB, but empirical, quantitative research is lacking. More research is needed to push reform and adequately prepare the future citizens of the 21<sup>st</sup> century. Innovative teachers and administrators in nimble learning communities may want to consider Physics First to begin propelling science education reform. Otherwise future educators, possibly in 2083, will be remarking about why a 200-year old, antiquated curriculum has endured for so

long. The science education community is implored to bury the traditionally taught BCP relic and consider implementing Physics First so that students can better achieve STEM literacy and physics can again be for *all*.

This study aimed to quantitatively describe the performance of PF and non-PF students at MRHS on a mathematics standardized test. Chapter 1 introduced the problem, purpose and significance of the study. Chapter 2 outlined the history of science education in the United States and reviewed the current research Physics First and how students learn. Chapter 3 will describe the methods of study and the quantitative data that was used in the study. Chapter 4 will present the results and Chapter 5 will discuss the results, share MRHS's story of modernization, and assert that a PF curriculum can address 21<sup>st</sup> century issues and science for all.

## **CHAPTER 3**

### **METHODOLOGY**

#### **Introduction**

This study evaluated the impact of a Physics First (PF-PCB) science program on SAT math scores at Matteo Ricci High School (MRHS) over the first two years of the program from 2007 to 2009. Reports show that students in the United States are underperforming in science, technology, engineering, and mathematics (STEM) when compared to their international counterparts. Secondary science education is in need of reform and modernization. MRHS transformed its science program to a Physics First model in an effort to improve learning and graduate STEM literate students. This study measured one of the objectives of the new program: improved math achievement.

This chapter describes the methods that were used in this quantitative study of the impact of a ninth-grade physics course on math achievement in a Physics First (PF-PCB) high school science program. Ex post facto measures from standardized math tests (High School Placement Test [HSPT] and SAT) at the school site were used to determine the math achievement of two groups of students in the same graduating class (cohort) over their high school career. The ninth-grade science course determined the two groups: those that took ninth-grade physics (PF) and those that took no science in the ninth grade (non-PF). Descriptive statistics and causal-comparative strategies were employed to determine the differences in student achievement on a standardized mathematics exam for the two groups of students. Where differences exist, inferential statistics were used to determine significance. The instruments that determined



mathematics achievement are introduced and described here. The research methods address the issue of self-selection and the limitations of the study's generalizability are discussed.

### **Site**

This investigation takes place at a private high school on the West Coast of the United States referred to by the pseudonym, Matteo Ricci High School (MRHS). Given the need for quantitative research of Physics First programs, MRHS provides a unique opportunity for science education research (Bardeen & Lederman, 1998; Lederman, 2005; Neuschatz et al., 2008; Pasero, 2003; Wilt, 2005). MRHS implemented a Physics First (PF-PCB) program in 2007 and in 2011 graduated its first cohort of students. These factors make MRHS a timely and suitable site for the proposed research. The researcher was employed by MRHS during the time of the study and was granted access to anonymous achievement data with proper permission.

MRHS is an ethnically diverse, private, college-preparatory high school (grades 9 through 12) in a large, highly diverse urban area. Annual enrollment is approximately 1200 male students who represent more than 200 zip codes and more than 100 elementary schools. The vast majority (99%) of the graduates go on to higher education and 96% enroll in four-year colleges. MRHS is committed to providing a rigorous college-preparatory education to a student body that reflects the racial, ethnic, and socially economic diversity of its surroundings. Fifty-two percent of the student body is non-white.

In the fall of 2007 the MRHS science department implemented change on a large scale. The traditional science curriculum sequence was inverted from biology first (BCP) to a Physics First (PF-PCB) program: Physics is offered to ninth-grade students; chemistry is mandatory for 10<sup>th</sup>-graders; and biology, or its equivalent, is mandatory for 11<sup>th</sup>-graders (see Table 1).

Table 1  
*MRHS Science Sequence of Core Courses Studied*

Grade 9	Grade 10	Grade 11
Physics First (PF) or no science (non-PF)	Chemistry or Honors Chemistry	Biology or equivalent

### **Participants**

The participants in this study consisted of all MRHS students in the first two graduating classes in the new PF-PCB program (N = 571). Cohort 1 (class of 2011) had 280 and Cohort 2 (class of 2012) 291 participants. The cohorts were 48% White/Caucasian; 29% Hispanic/Latino; 12% Asian/Pacific Islander/Filipino; and 11% African American/Black. Most students commute from far distances to attend MRHS and represent nearly 200 zip codes. This combined with the mission of the school attracts students from a wide range of SES. Zip code data show students living in areas with median incomes as high as \$141,527 and low as \$17,644. Student math ability is more homogeneous than ethnicity/race and SES due to the selective nature of admissions. Data show that on average students with higher High School Placement Test (HSPT) math scores chose to participate fully in the new Physics First program by taking ninth-grade physics (PF).

### **Ethnicity/Race**

Students were given the opportunity to indicate their ethnicity/race (ethnicity) when taking the SAT and the HSPT. These data showed that there was a significant difference in the ethnic/racial makeup of PF and non-PF groups in Cohort 1 but not in Cohort 2 (see Table 2). Specifically, in Cohort 1 African American/Black and Hispanic/Latino students were

overrepresented in the non-PF group in Cohort 1 ( $X^2 = 18.27, p = .006$ ): meanwhile, these groups were distributed similarly in Cohort 2 ( $X^2 = 8.78, p = .186$ ).

Table 2  
*Ethnic/Racial Differences in Cohorts 1 & 2*

	Cohort 1*		Cohort 2	
	PF	non-PF	PF	non-PF
American Indian/Alaskan Native	2	0	0	0
Asian American/Pacific Islander	16	4	16	5
African American/Black	13	17	18	16
Hispanic/Latino	42	51	51	29
White/Caucasian	88	46	104	45
Filipino	10	7	9	6
Other	0	0	0	2
Unknown	1	2	2	1

\* $p < .05$

### Socioeconomic Status

SES was determined from median household income data published by zip code (Zip Atlas, 2012). Zip codes accompanied SAT math scores and HSPT data. The average median household income values were compared for each cohort. In Cohort 2, students in the PF and non-PF groups were similar in terms of SES, but were significantly different in Cohort 1 ( $t(278) = 2.49, p < .05$ ). In Cohort 1, the non-PF group was overrepresented by low SES minority students.

Table 3  
*SES Differences in Cohorts 1 & 2*

	N	Cohort 1*		N	Cohort 2	
		M	SD		M	SD
PF	166	\$63,017.70	\$29,074.83	193	\$62,370.99	\$29,164.57
Non-PF	114	\$55,125.72	\$24,405.81	98	\$60,140.18	\$28,580.41

\* $p < .05$

### **Prior Math Achievement: HSPT Math**

PF and non-PF groups were determined non-randomly; students were given the choice to take ninth-grade physics (PF) or no science (non-PF). It was assumed that higher achieving math students were more likely to enroll in ninth-grade physics (PF) than their lower performing counterparts. This type of self-selection naturally positions students more advanced in math to achieve higher SAT math scores.

Significant differences in prior math achievement existed between PF and non-PF groups in both cohorts; higher achieving math students were overrepresented in the PF groups (see Table 4). In terms of prior math achievement, PF and non-PF groups were significantly different in both Cohort 1 ( $t(278) = 3.14, p < .001$ ) and Cohort 2 ( $t(289) = 3.39, p < .001$ ) (Table 4). Effect size ( $r$ ) for Cohort 1 was 0.19 and 0.22 for Cohort 2.

Table 4  
*Math Achievement Differences in Cohorts 1 & 2*

	<u>Cohort 1*</u>			<u>Cohort 2*</u>		
	N	M	SD	N	M	SD
PF	166	86.13	15.47	193	87.99	13.85
Non-PF	114	78.71	21.74	98	80.23	20.59

\*  $p < .001$

### **Research Question**

Do Physics First (PF) students in the Physics First program (PF - Physics - Chemistry - Biology) at Matteo Ricci High School (MRHS) have higher SAT math scores than their non-PF counterparts (Chemistry - Biology) when controlling for prior math achievement, race/ethnicity, and SES?

## **Variables**

The independent grouping variable (IV) is the PF-PCB program. PF represented the students that took ninth-grade physics, 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology, and non-PF represents those that did not take ninth-grade science, but took 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology with their PF peers. It should be noted that PF has dual meanings in this study. First, PF identifies those students at MRHS that take ninth-grade physics and continued through the program with their non-PF peers. Secondly, PF commonly refers to a secondary science program like MRHS's that simply begins with physics; as such, there are other variations of PF (e.g., PBC). The curricular order of the MRHS PF program is physics, chemistry, and biology (PCB). Thus, PF-PCB more accurately represents the MRHS program in this investigation. In this context the term "biology last" may be a more appropriate descriptor, but Physics First has been well established since Leon Lederman, an influential science education reformer, argued for the PCB sequence and promoted it with the slogan "put physics first" (Lederman, 2001). Those students that chose not to take physics will be referred to as non-Physics First students (non-PF). It is important to note that both PF and non-PF students move through the curriculum with their cohort by taking 10<sup>th</sup>-grade chemistry and 11<sup>th</sup>-grade science course (i.e., biology or its equivalent) together. PF and non-PF students indicate the grouping variable that was used to compare SAT math scores, the dependent variable, after completing the PF-PCB program.

## **Hypothesis**

PF students in the PF-PCB program at MRHS will have higher SAT math scores than their non-PF counterparts, while controlling for their prior math achievement, race/ethnicity, and SES.

The null hypothesis was: A significant difference does not exist between PF and non-PF SAT math scores in both Cohorts 1 and 2 at MRHS. The prediction of this study was that the null hypothesis would be rejected and that PF has a positive impact on SAT math scores; PF students score higher on the SAT math when controlling for prior math achievement, ethnicity/race, and SES.

### **Sampling Method**

This causal comparative, quasi-experimental study used data from the first two cohorts of students that completed all four years of the Physics First (PF-PCB) program at MRHS. Within each of these cohorts the independent variable was determined by participation in ninth-grade physics (PF). Cohort 1 was the inaugural class of the new PF-PCB program, the graduating from MRHS in 2011. Cohort 2 represents the class of 2012. Each cohort was comprised of approximately 300 students where two-thirds chose to take PF and one-third chose no science in the ninth grade (non-PF); there were 166 and 193 PF students, and 114 and 98 non-PF students, in Cohorts 1 ( $n_1 = 280$ ) & 2 ( $n_2 = 291$ ), respectively ( $N = 571$ ).

After ninth grade both PF and non-PF students in Cohorts 1 and 2 had the same access to science classes in the subsequent years (10<sup>th</sup> through 12<sup>th</sup> grades). This means that PF and non-PF students were mixed in science courses after the ninth-grade year. This study aimed to determine the difference in math achievement of PF and non-PF students after completing the three-year MRHS Physics First (PF-PCB) program.

While students chose whether to take science in the ninth grade (PF) or not (non-PF) at MRHS, they were placed into a math course based on ability. The Mathematics Department used the HSTP math and placement exam scores to determine the appropriate course for each student.

Scores on this test determined their proficiency and preparedness for the next course in the sequence. Unlike science, enrollment in ninth-grade math was based on a test scores and placement. These mathematics courses (i.e., Algebra, Algebra Accelerated, or Geometry) contained a mixture of PF and non-PF students. Thus, there was a range of mathematical ability in both PF and non-PF groups. Student SAT math scores were compared after completing three years of schooling. These scores are typically recorded late in the 11<sup>th</sup> grade and early in the 12<sup>th</sup> grade. To better determine the impact of ninth-grade physics on SAT math scores the influence of prior math ability needed to be addressed.

### **Self-Selection.**

Self-selection was a threat to validity in this study. Students, or parents of students, chose whether to take ninth-grade physics (PF) (the independent grouping variable) or no science (non-PF); students were not randomly assigned to these groups. While three years of laboratory science are required at MRHS, ninth-grade science is optional: taking ninth-grade physics (i.e., selecting to be PF) is a choice. One might presume that students with a high interest or aptitude in mathematics choose the course. The researcher attempted to address this assumption by analyzing the achievement in mathematics of PF and non-PF students before the PF-PCB treatment.

Extant data were used to determine the pre-existing differences between the PF and non-PF groups in mathematics. MRHS students take the HSPT prior to enrollment. PF and non-PF HSPT math scores were compared using a *t*-test to establish that indeed PF and non-PF groups were significantly different in prior math achievement (Cohort 1:  $t(287) = 3.19, p < .05$ ; Cohort 2:  $t(296) = 3.38, p < .05$ ). This analysis confirmed the assumption that higher-achieving math

students (Cohort 1:  $M = 86.13$ ,  $SD = 15.47$ ; Cohort 2:  $M = 87.99$ ,  $SD = 13.85$ ) were more likely to select the PF option and take ninth-grade physics compared to students who selected the non-PF option (Cohort 1:  $M = 78.71$ ,  $SD = 21.74$ ; and Cohort 2:  $M = 80.23$ ,  $SD = 20.59$ ). In both cohorts, the data show that students with higher HSPT math scores were over-represented in PF treatment group.

In addition, students may have self-selected to take PF or non-PF courses based on their backgrounds; as such, SES and ethnicity/race data were analyzed to determine inherent differences in the groups. Differences in SES, recorded as median income of residential zip code reported by students, were examined via a  $t$ -test. For Cohort 1, a significant difference was found ( $t(278) = 2.49$ ,  $p < .05$ ) such that students from higher socio economic backgrounds ( $M = \$63,018$ ;  $SD = \$29,075$ ) took PF compared to those in lower socio economic backgrounds ( $M = \$55,126$ ;  $SD = \$24,405$ ). No significant difference was found for Cohort 2 ( $t(302) = .64$ ;  $p = .525$ ). Likewise, more White students were represented in the PF curriculum than other ethnicities ( $\chi^2 = 18.27$ ;  $p < .05$ ) for Cohort 1, but no significant differences in ethnicity were noted ( $\chi^2 = 8.79$ ;  $p = .186$ ) in Cohort 2.

### **Measures of Achievement**

This study determined the impact of the PF-PCB program on SAT math scores at MRHS. All students at MRHS take the SAT in the 11<sup>th</sup> and 12<sup>th</sup> grades in preparation for college admission. The SAT, produced by the College Board, is a common test for college admissions and consists of three sections. Only the mathematics section of the SAT was used in this study. Thus, the SAT offered a terminal measure of high school achievement in mathematics. Comparing PF and non-PF student scores on this section of the SAT answered the research



question: Do Physics First (PF) students in the Physics First program (physics–chemistry–biology) at MRHS have higher SAT math scores than their non-PF counterparts (chemistry–biology) when controlling for prior math achievement, race/ethnicity, and SES?

### **Procedures**

After receiving permission from both the Institutional Review Board at Loyola Marymount University and the administration of MRHS anonymous SAT math data were electronically delivered from the Director of Counseling. The data were downloaded and backed up on an external drive that remained solely in the possession of the researcher. At no point were the names of students available. Identification numbers were randomly assigned to individual students and their scores and demographic data were coded accordingly.

### **Data Analysis**

An Analysis of Covariance (ANCOVA) was used to control for prior math achievement (HSPT math), SES, and ethnicity/race and determine the influence of the ninth-grade physics course in the PF-PCB program on SAT math scores.

### **Limitations**

One limitation is the site of study. Like any learning community, MRHS is unique. The culture, conditions, and components of learning are complex and may have influenced results. The researcher used quantitative methods to determine achievement by using available test scores. A deeper, qualitative description of the site, the potential application of results, and suggestions for future research will be found in Chapter 5.

## Summary

Chapter 3 described the methods that were used in this longitudinal, quantitative, quasi-experimental, study. Causal-comparative strategies were employed to determine the differences in student achievement on standardized mathematics tests for two groups of students: those that took ninth-grade physics (PF) to those that chose not to take science in the ninth grade (non-PF) at MRHS. Ex post facto measures of standardized math tests (HSPT and SAT) were used to determine math achievement of PF and non-PF students. The HSPT was used to determine prior math achievement and confirm that higher-achieving math students chose to participate in the Physics First program by taking ninth-grade physics. The math section of the SAT provided a measure of math achievement after the PF-PCB program.

Inferential statistical methods were used to determine the differences in PF and non-PF groups. The data confirmed that the PF group was over-represented with high-achieving math students in both cohorts. Interestingly, in addition to differences in math scores, the PF group in Cohort 1 also differed significantly from the non-PF group in both SES and ethnicity/race; the PF group of Cohort 1 was over-represented by White, high SES students. This was not the case in Cohort 2 as there was no significant difference in the areas of SES and ethnicity/race. As such, an Analysis of Covariance (ANCOVA) was selected to determine the impact of the PF-PCB program on SAT math scores. This analysis provides the necessary results to compare groups of PF and non-PF students and answered the research question. The results of this analysis are presented in Chapter 4. Chapter 5 will discuss the results and the implications.

## **CHAPTER 4**

### **RESULTS**

#### **Introduction**

The purpose of this study was to quantify the influence of a new Physics First (PF-PCB) science program on students' math achievement at MRHS. Reports show lackluster performance by students in the United States in the areas of science, technology, engineering, and mathematics. Secondary science education is in need of reform and modernization. MRHS transformed its science program to a PF-PCB model in an effort to improve student learning and graduate STEM literate students. This study measured one of the objectives of the new program: improved math achievement.

PF-PCB represents the type of Physics First program under investigation—as opposed to Physics First—physics, biology, and chemistry (PF-PBC). The traditional sequence in the United States is biology, chemistry, and physics (BCP). Students in the PF-PCB program at MRHS are referred to as Physics First (PF) students and their counterparts that choose not to enroll in the program are non-Physics First (non-PF) students.

The study evaluated MRHS's first two cohorts of students to complete the PF-PCB science program, the classes of 2011 and 2012 (Cohort 1 and Cohort 2). The instrument for math achievement (DV) was the mathematics section of the SAT (SAT math), typically recorded either late in the junior or early in the senior year. This study compared SAT math scores of students that took ninth-grade physics (PF) to those that did not (non-PF), but finished the rest of the program together through the 11<sup>th</sup> grade.

The ninth-grade science course, PF or non-PF, was the independent grouping variable (IV) of the study; students in the PF group took ninth-grade physics, chemistry in the 10<sup>th</sup> grade, and biology or an equivalent life science in the 11<sup>th</sup> grade. Non-PF students took chemistry and life science alongside their PF classmates in subsequent years, but did not take science (i.e., physics) in the ninth grade. This primary difference determined the groups: PF and non-PF. Students that took ninth-grade physics were designated PF and students that did not take ninth-grade science were designated non-PF. This study evaluated the contributions of PF (IV) on SAT math scores (DV) while controlling for three factors: SES, ethnicity/race, and prior math achievement.

### **Analysis of Data**

This study evaluated the impact of the ninth-grade physics course at MRHS on SAT math scores over the first two years (2007 – 2009) of the Physics First program (PF-PCB). Secondary science programs in the United States seek to improve student achievement in the STEM disciplines. MRHS provides the opportunity to evaluate the impact of a Physics First curriculum on math achievement and inform the body of research. While the MRHS student body is diverse in terms of SES and ethnicity/race, the PF and non-PF groups were not randomly assigned; students self selected in to the ninth-grade physics course and pre-existing differences existed between the groups.

Due to pre-existing differences and the potential for self-selection in to the ninth-grade physics course a one-way Analysis of Covariance (ANCOVA) was used to evaluate math achievement while controlling for SES, ethnicity/race (ethnicity), and previous math achievement. The ANCOVA was the appropriate analysis given the significant differences in

SES, ethnicity, and prior math ability (HSPT math) and the ANCOVA provides a better sense of the influence of the ninth-grade physics course (PF) on SAT math scores.

**PF and non-PF Differences**

**SAT math.** PF and non-PF students differed in math achievement. Cohort 1 PF students outperformed ( $M = 643.43, SD = 90.36$ ) their non-PF counterparts ( $M = 611.58, SD = 83.34$ ) by 31.85 points; Cohort 2 PF students outperformed non-PF students by 44.15 points (PF  $M = 647.62, SD = 84.57$ ; non-PF  $M = 603.47, SD = 73.91$ ) (see Table 1). However, *t*-tests showed that the difference in means were not significant for both Cohort 1 ( $t(278) = 2.94, p = 0.338$ ) and Cohort 2 ( $t(289) = 4.63, p = .100$ ) without controlling for other factors (see Table 5).

Table 5  
*Original SAT Math Differences in Cohorts 1 & 2*

	Cohort 1			Cohort 2		
	N	M	SD	N	M	SD
PF	166	643.43	90.36	193	647.62	84.57
Non-PF	114	611.58	83.34	98	603.47	73.91

\*  $p < .05$

These differences in math achievement between PF and non-PF students do not account for selection bias however, particularly pre-existing group differences. This study examined three areas of interest that have contributed to the achievement gap in the United States: socioeconomic status (SES); ethnic and/or racial identity (ethnicity); and pre-existing math achievement (HSTP math).

**Controlling for SES, ethnicity/race, and prior math achievement.** In order to account for self-selection and pre-existing differences, this study used an Analysis of Covariance (ANCOVA) to control for differences in the PF and non-PF groups, particularly math

achievement. The ANCOVA statistically adjusted the SAT math means by determining the influence of the covariates and determined their contributions to higher SAT math scores.

ANCOVA results (Table 6) adjusted for these factors to decipher the influence of ninth-grade physics (PF) on SAT math scores. Controlling for SES, ethnicity, and prior math, students in PF scored significantly higher on SAT math scores ( $F(1,286) = 6.72, p < .05$ ) in Cohort 2; however, the ninth-grade physics course (PF) did not contribute significantly to the differences found in Cohort 1 ( $F(2,279) = 0.58, ns$ ).

Table 6  
*Differences across Cohorts 1 & 2*

	Cohort 1			Cohort 2			df
	M Sq.	F	Sig.	M Sq.	F	Sig.	
SES	3053.655	0.640	.424	1238.615	.292	.589	1
Ethnicity/Race	6223.266	1.305	.254	2687.548	.634	.427	1
HSPT Math	749418.050	157.146	.000*	649943.898	153.294	.000*	1
PF	2778.600	0.583	.446	28494.994	6.721	.010*	1

\*  $p < .05$

Table 7 shows the adjusted SAT math scores for both Cohort 1 and 2. In Cohort 1 the 6.6 point difference in SAT math mean scores is not significantly different for the students that took ninth-grade physics (PF) ( $M = 633.161, SE = 5.432$ ) versus non-PF ( $M = 626.538, SE = 6.595$ ) even after controlling for SES, ethnicity/race and prior math achievement (HSPT math). But in Cohort 2 the 21.4 difference in adjusted SAT math mean scores does differ significantly for PF ( $M = 639.972, SE = 4.726$ ) versus non-PF students ( $M = 618.525, SE = 6.684$ ) when controlling for SES, ethnicity/race and prior math achievement (HSPT math). In the second cohort at MRHS, the ninth-grade physics (PF) course contributed significantly to higher math achievement (SAT math scores). Effect size ( $r$ ) for Cohort 1 was 0.18 and 0.27 for Cohort 2.

Table 7  
*Adjusted SAT Math Means in Cohorts 1 & 2*

	Cohort 1		Cohort 2*	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
PF	633.161	5.432	639.972	4.726
Non-PF	626.538	6.595	618.525	6.684

\*  $p < .05$

a. Covariates appearing the cohort 1 model are evaluated at the following values: *SES* = \$59,952.75, *Eth/Race* = 4536, *HSTPmath* = 83.11

b. Covariates appearing the cohort 2 model are evaluated at the following values: *SES* = \$61,700.05, *Eth/Race* = 4811, *HSTPmath* = 85.30

### Conclusion

In the second year of the Physics First (PF-PCB) program at MRHS, students who were enrolled in the ninth-grade physics course (PF) scored on average 21.4 points higher on the SAT math test. An ANCOVA revealed that the ninth-grade physics course (PF) had a significant ( $p < .05$ ) impact on math achievement in Cohort 2. In Cohort 1, this effect was undetected. In the first year of the program, the PF group did not score significantly higher than the non-PF group. These findings emerged after controlling for SES, ethnicity/race, and prior math achievement (HSPT math). Reasons for these differences are outlined in Chapter 5.

## **CHAPTER 5**

### **DISCUSSION**

#### **Introduction**

This chapter discusses the results of this study and shares a richer description of MRHS's story of transformation in its effort to advance STEM education. The study evaluated the impact of a Physics First (PF-PCB) science program on the SAT math section scores at MRHS over five years (from 2007 to 2012) after the first two classes (Cohort 1 & 2) had completed the new PF-PCB program. The study responded to the calls for more quantitative evidence of PF programs (Neuschatz, McFarling, & White, 2008; O'Brien & Thompson, 2009; Pasero, 2003) and the need to address the underperformance of students in science and math in the United States (Bybee, McCrae, & Laurie, 2009; Gonzales et al., 2008; Martin et al., 2012; NRC, 2007).

Secondary science education is in need of reform and modernization in order to advance STEM education in the 21<sup>st</sup> century (NRC, 2007). MRHS transformed its science program to a PF-PCB model with inquiry- and project-based learning in an effort to graduate scientifically literate students. This study measured one of the objectives of the new program: improved math achievement as measured by the math section of the SAT test.

#### **Description of Results**

The study found that the PF-PCB program at MRHS had a significant impact on math achievement in the second cohort of students. The findings confirm that students who chose to take ninth-grade physics (PF) and completed the subsequent curricular sequence (PCB) scored higher on the SAT math than their non-PF (no ninth-grade science) counterparts while controlling for pre-existing differences in math ability. According to the findings, the PF-PCB



program contributed 21.4 points on the SAT math test for Cohort 2. As such, the students (PF) who completed the PCB sequence (ninth-grade physics, 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology) significantly improved SAT math test scores compared to students (non-PF) who experienced only 10<sup>th</sup>-grade chemistry and 11<sup>th</sup>-grade biology (CB). As a result, the inversion of the traditional program of 10<sup>th</sup>-grade biology, 11<sup>th</sup>-grade chemistry, and 12<sup>th</sup>-grade physics (BCP) to PCB appears to have been successful in accomplishing one of the objectives: improvement in math achievement. In addition to an inverted curricular sequence, the PF-PCB program at MRHS was characterized by technology-rich, inquiry- and project-based teaching methods. After the first year of the PF-PCB program the class of 2012 (Cohort 2) showed significant gains in SAT math scores that could be attributed to the PF-PCB program. These findings emerged after controlling for socioeconomic status (SES), ethnicity/race (ethnicity), and prior math achievement (HSPT).

In Cohort 1 (the class of 2011), however, this effect was undetected. The slightly higher SAT math scores of the PF group were insignificant and could not be attributed to the PF-PCB program. Based on my roles as MRHS science department chair from 2005 to 2011 and leader of the implementation the PF-PCB program, I am positioned to offer an explanation and some speculation as to why these differences occurred. I argue that the differences in the first two years of the program offer the best explanation to why the desired effect of higher SAT math scores was found in Cohort 2 and not Cohort 1.

### **Explanation of Results**

The PF-PCB program yielded different results in its first two cohorts because the first year was much different than the second. While both cohorts had higher achieving math students

in the PF group, Cohort 1 differed from Cohort 2 in terms of race/ethnicity and SES. In Cohort 1, the PF group was overrepresented by high-SES, White students and the non-PF group was overrepresented by non-White, low-SES students. In Cohort 2 the PF and non-PF groups were similar across the board in terms of SES and race/ethnicity. While the study used statistical methods (ANCOVA) to control for the influence of these factors on SAT math scores, the fact that these differences existed among students who self-selected in to the ninth-grade physics course suggests there was an issue of perception during the first year of the PF-PCB program. I argue that this perception was stronger in the first year (Cohort 1) than the second (Cohort 2). Incoming students and their parents were unfamiliar with and more skeptical of the ninth-grade physics course. While the course was designed for all incoming ninth-graders the perception was that course was like the traditional 12<sup>th</sup>-grade course and thus suited to the mathematical elite, as evidenced by the higher math scores and racial/ethnic imbalance of the PF group. In the second year of the program, more non-White and lower SES students began to enroll in the course, including those that had higher math ability. It appears that after the first year of the program, a more diverse group of students chose to take the ninth-grade physics course. Perhaps some fears were alleviated after one cohort had completed the program, familiarity grew, and stories of success and inclusion were shared.

Second, the first year of the PF-PCB program presented teaching challenges that the second year did not present. In essence, the first year was a rehearsal for the second. Howard Glasser (2012) found a similar pattern when he investigated the differences in math achievement over seven years between students in a school's BCP and PF-PCB programs. The school inverted

its sequence and improvement in math scores followed, except the effect was minimal in the first year. Glasser (2012) indicated:

The improvement was less marked for the first class to take physics than for the next two classes. This difference could have arisen because... the program might have gained greater familiarity with teaching ninth-graders physics as time passed and they developed more, or better, curricular material for this course. (p. 54)

This explains the improved student scores in the second year (Cohort 2) of the new program at MRHS. When the first class (Cohort 1) entered the PF-PCB program in 2007, nearly everything was new for MRHS science teachers. It was as if every teacher were a new teacher. We were all trained to teach in a non-traditional fashion using new materials in new facilities. The newness was exciting, but teachers expressed discomfort with and lack of confidence in the new teaching methods and corresponding curriculum. Inquiry- and project-based methods and alternative assessments were sources of frustration and forced teachers to question the value of their efforts. Glasser's (2012) findings highlight a limitation of the study that teaching and variations in teaching methods may contribute more to student learning than curricular order. It also indicates that sequencing curriculum is not enough, quality teaching must accompany curriculum changes.

Teachers at MRHS persevered and supported each other, and as the year progressed, they became more adept at teaching using these non-traditional means. After the first year of the PF-PCB program, teachers were more comfortable and capable, and as a result their practice improved, and so did student learning. In Cohort 2, PF (physics–chemistry–biology) students had significantly higher SAT math scores than their non-PF (chemistry–biology) counterparts, even when controlling for their prior math ability.

## **How Students Learn Science**

The conceptual framework for this study was grounded in constructivism (Bransford & Brown, 2000; Bybee, 2009a, 2009b; Bybee et al., 2006; Donovan & Bransford, 2005, 2007). Donovan and Bransford (2005) applied modern learning theory, deeply rooted in constructivism, to science education. A constructivist approach optimizes the learners' prior knowledge and experiences, so as to build a stronger conceptual base over time by assimilating new concepts into the context already established within each individual. The idea is context over concept, application over memorization. The results found in this study demonstrated that when the sequence was conducive to learning and the teaching improved after the second year. Constructing learning and practices STEM skills in context improved achievement in mathematics without altering the math curriculum.

## **Future Studies**

### **Baseline Data: Attitudes, Knowledge, and Skills.**

Future studies are needed to address and better quantify the other potential impacts of a PF-PCB program on achievement and scientific literacy. For programs considering inverting their curriculum, baseline data are critical to evaluate the influence of the program. For example, data on student attitudes towards science, knowledge, and skills (i.e., practices) are needed to determine the other potential effects of an inquiry-driven PF-PCB program. Also, if possible, all students should be assigned to the program, or at least randomly assigned, to better determine the impact of the program and minimize self-selection bias. Further, a PF-PCB program must evaluate the effect of having physics and chemistry before biology. Given the line of reasoning for placing biology last, it is reasonable to expect deeper understandings and higher achievement

in microbiology and molecular chemistry. Lastly, since most physics courses remain relegated to the 12<sup>th</sup> grade for the math elite and enrollment typically over-represents White males, I urge the investigation of the impact of offering this most foundational course to those that are underrepresented and underserved, and the longitudinal evaluation the influence of granting access to physics in the ninth grade to *all* (Eisenkraft, 2010).

### **Gender Gap in Science**

It has not escaped my notice that this study may have been influenced by gender. This investigation has implications for future studies in the areas of single-sex education and gender studies in science. I acknowledge that the all-male student body at MRHS was a limitation, and I now argue that a need exists to better understand the gender gap in science, especially physics, so that it can be for *all*. Taasobshirazi and Carr (2008) reported that gender differences are greatest in physics and proposed a new approach (i.e., framework) to investigate these differences. They reported “there are gaps in both the research on the development of expertise in physics and the research on gender differences in science” (p.162).

Studies of programs like PF-PCB are needed in various school settings, including all-female and coeducation institutions, both private and public. For those interested in how boys and girls learn math and science in single-sex environments, whether in a single-sex institution like MRHS or in a single-sex classroom on a coeducational campus, studies are needed to evaluate the effects of PF-PCB on achievement. These studies would not only inform the Physics First debate, but would address the need to better understand the underrepresentation of females in physics.

## **Implications and Recommendations**

If other schools wish to replicate this study I urge them to collect data before, during, and after implementation. In addition to measures of achievement in math and science, measures of students' inquiry skills, attitudes toward science, and understandings of the nature of science are needed. In this regard, common metrics need to be designed to evaluate students' skills and understandings in science. In addition, a common and widely accepted measure of scientific literacy is needed. This would better match the goal of increasing scientific literacy rather than simply measuring mathematical and scientific facts and knowledge. More PF schools and better instruments are needed to assess STEM-related goals.

Research from single-sex high schools are needed to inform the PF debate, particularly all-female, Catholic schools. Bryk, Lee, & Holland, (1993) found that achievement gains in the areas of math and science had a larger effect in all-female school compared to coeducational institutions (p. 237). I urge Catholic all-female schools to consider implementing PF and to measure science and math achievement, attitudes toward science, scientific practices, and the understandings of the nature of science. This type of research will not only inform the PF debate, but may illuminate issues that contribute to the gender gap in science, particularly physics.

### **Using the Results: Sharing and Modeling Growth**

The results presented in this study demonstrate that a PF-PCB program can have an impact on math achievement. I urge more schools like MRHS to embark on the journey of change, to document and measure their progress, and to formally share the results in an effort to improve STEM education nationwide. Since MRHS is a private, Catholic school, decision-making is site-based. This level of autonomy and shared-leadership can allow for nimbleness and

adaptability, if administrators are convinced, courageous, and willing to change. PF is more likely to be an option at sites with a similar context to that of MRHS; this study may be less generalizable to large school districts, and more generalizable to independent schools with the authority to unabatedly choose to test and implement new curriculum, instructional methods, and assessments.

In order to further share the story of the transformation of the MRHS, science program I will give a richer description here. The following section will show that with a shared vision, empowered teachers, and effective leadership, secondary schools in the United States can transform their programs in to a more coherent and effective programs by re-sequencing the big ideas in science and focusing on inquiry practices and student attitudes in science. MRHS's story of transformation is shared here so that others may be inspired to grow and continue the march of change in secondary science education.

## **A Story of Modernization and Advancement Toward STEM Education**

### **Introduction**

The story of transformation of the secondary science program at MRHS is presented in this section and has the following structure. The need for change and the challenges facing STEM education are revisited. An overview of the conditions for change at MRHS is shared. This includes discussions of the impetus for change, the empowerment of teachers, the target learners (the *who*), the focus on STEM literacy, the need for coherence, and the ultimately, the decision for and dedication to change. Next the reasoning for the curricular (*what* and *when*) change is presented. The history of science education in the United States provides the context of the problem for MRHS teachers. Teaching methods and assessment (*how*) are addressed

followed by the importance of student attitudes and the understanding the nature of science (*why*). Lastly, results from the study and other data that demonstrated the culture of growth and evidence for success are shared. While the work is never finished, the paper concludes by framing MRHS's culture of growth, reflection, and evaluation in the new *Framework* (NRC, 2012), the Next Generation Science Standards [NGSS] (NRC draft, 2013), and leadership for social justice.

## **Background**

Reports of the past two decades continually remind us of the dire state of science education in the United States. These reports then call for changes in curriculum, teaching and assessment in our schools. The science department at MRHS accepted the challenges of these reports and embarked on a journey of change. The new science program addressed the *what*, *when*, *how*, and *why* of learning: the curriculum, sequencing, instruction, and attitudes towards science. The poet Antonio Machado remarked, “there is no road, the road is made by walking” (1912). This section will map out MRHS's journey with the hope that the path forged will further our understanding of how change in science instruction can occur and better serve *all* students.

A clear need exists for reform in secondary science education in the United States. Wilt (2005) said “Science education must change – and change soon. The amount of technical information available to humanity doubles every few years, and this information eventually makes its way into the high school science curriculum” (p. 360). The gap between scientific discovery and science education is growing; the pace of change of the former increases while the latter remains the same. Student achievement in science remains a concern. Reports like *A Nation at Risk* (NCEE, 1983), the 2007 *Trends in International Mathematics and Science Study*



(TIMSS), the 2009 *National Assessment of Educational Progress* (NAEP), the 2006 and 2009 *Programme for International Student Achievement* [PISA] (Bybee et al., 2009), and the most recent publication of *The Nation's Report Card* (NCES, 2011) have documented the lackluster performance of American students in science. To better prepare a scientifically literate and capable citizenry to meet the challenges and opportunities of the 21<sup>st</sup> century, student achievement in science must improve and student access to science must be addressed. Traditional models in secondary science programs need to be questioned and alternative models considered and evaluated to improve student learning and access to science.

MRHS implemented a new science program in 2007 in an effort to improve student learning. At that time the science teachers were empowered to design and implement a modernized science program. The design of the new program was driven by *what* high school students should know and be able to do (curriculum and assessment); *when* they should know and do it (sequence); and *how* to best instruct them (teaching) while capitalizing on students' natural curiosity and motivation to explicitly link *why* (relevance) the content and skills are interesting and important. MRHS embarked on a complete transformation of its curriculum, instruction, and assessment, and used science education research and national standards to guide the process.

Research and standards propelled the MRHS science program towards inquiry-based instruction, project-based learning, and a more consistent and coherent curriculum (Bybee, 2009). The *National Science Education Standards* [NSES] (NRC, 1997) outlined the content objectives and made the case for teaching science through the inquiry. Research on how students learn (Donovan & Bransford, 2005) and publications like *Inquiry and the National Science*

*Education Standards* (NRC, 2000) provided substantial guidance for choosing *inquiry* as the central theme of learning and teaching. This focus on student learning through inquiry and the efforts to advance STEM education (NRC, 2011) led to new instructional methods that valued students' cognitive skills, science practices, and attitudes toward science.

In addition to inquiry methods and a more coherent curriculum, the other parts of STEM were addressed. Meaningful technology was introduced in the science classrooms and coordination with the Mathematics Department began. Engineering and design principles were explicitly embedded in courses and student projects. This work was not completed. As new insights emerge from the NRC's (2012) *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and the NGSS (NRC draft, 2013), the teachers, administration, and students will continue to shape their science program.

### **Overview of the Program: The *What, When, How, and Why* of Learning**

MRHS's new science program addressed the *what, when, how, and why* of learning: the curriculum, sequencing, instruction, and student attitudes towards science. A key to successful implementation was the empowerment of science teachers with decisions regarding each of these components of a science program. Science teachers felt compelled to upgrade the science program as the school broke ground on new science facilities. Teachers felt obligated to begin anew and discard outdated materials, curriculum, and instructional methods. The new laboratories inspired new thinking and were the impetus for re-evaluation of the science program. It forced the MRHS science teachers to ask questions about what all students should know and be able to do by the time they graduate. The science department challenged itself to find the best program in secondary science education and launch it. This challenge unified the

department and led its members on a journey of inquiry as they researched various programs and methods of teaching. The teachers concluded that not only did they want to change *what* they taught (core curriculum), but also *how* (instruction) they taught it, and *when* (sequence) it should be taught, meanwhile addressing the students' underlying question, "*why* learn it?" (relevance).

### **Empowered Teachers and Educational Leadership**

With shared power and the challenge to advance STEM education, department members were faced with important pedagogical questions. They had to address their beliefs about how student learn science and discuss what should be taught, the nature of learning, how teachers should teach, and how learners should be assessed (Cullen, Harris, & Hill, 2012). The empowerment of science teachers and the development of shared beliefs were key components to improving the science program at MRHS. This fostered strong collaboration and professionalism among the teachers. Over two years, the science faculty considered various programs to adopt and dedicated time on weekends and during the summer to review the science education literature, to attend regional and national conferences (CSTA & NSTA), and to consult with science education professors. Approximately two hundred person-hours over this time were dedicated to researching ways to improve student learning at MRHS. Armed with evidence and examples of possible curricula and instructional methods, the department met monthly for one-hour meetings to engage in important discussions. In these meetings, goals began to emerge, student learning became the priority, and the science teachers at MRHS began to design a program with the end in mind (Wiggins & McTighe, 2005).

**Target learners: *All students.*** In spite of MRHS's reputation for high-achieving students and college-preparation, teachers were confronted with the reality that student learning

and access to accelerated (honors and AP) classes could be improved with a better core curriculum and more effective instruction. First, the existing curriculum lacked coherence and consistency and did not provide a common foundational base of scientific knowledge and skills. Second, while most students completed three years of science, the majority of students were unable to choose four years of science or take honors or AP courses. The science department, inspired by the clarion call of “science for all,” (AAAS, 1990) desired a core program that could better serve more students.

Prior to implementation of the new program MRHS, students could graduate with much different experiences in science. The curriculum lacked coherence and consistency, and instructional methods were primarily didactic with little room for inquiry and scientific practices. No introductory course existed that laid the foundation for the subsequent courses; depending on enrollment, students were placed either in a biology or earth science course. In addition each biology teacher used a different text and emphasized different content. For example, 10<sup>th</sup>-grade students assigned to take biology could get a human approach, a molecular approach, or an ecological approach, depending on the teacher. No consistency between courses and no explicit connection to subsequent courses existed. Teaching and planning was done in isolation and there were no common course objectives. Teachers were missing out on the potential advantage of building concepts over time and capitalizing on common experiences. Further, inquiry methods were sparse and there was no discussion among teachers regarding what students should be able to *do* by the end of each course. Scientific practices were not a priority. One class might spend five hours of the year in the lab while another would spend twenty. Most time in the lab was spent simply confirming lecture material rather than investigating new lines of inquiry. Inquiry-

based labs go beyond merely confirming what students have learned; these experiences allow for different, more creative approaches to an investigation that open the possibility that students might learn or confirm something they did not already know. Consistency was needed in the curriculum and teaching methods as recommend by many national reports (BSCS, 2006; NRC, 2007, 2012, 2013).

Ultimately the decision to implement a completely new curriculum and inquiry- and project-based learning at MRHS was driven by student learning. Teachers were driven by the question: What should a scientifically literate graduate at graduation at the MRHS know and be able to do? The primary objectives were to graduate students with core scientific knowledge, practices, skills, understandings, attitudes towards science and appreciation of the nature of science that would promote a scientifically literate citizenry and enhance opportunities to pursue science in college and careers. Science teachers wanted go beyond just *knowing* science; they wanted graduates of MRHS to be able to *do, use, and discuss* about science. The goal was to graduate *STEM literate* citizens (NRC, 2007). To achieve this goal, MRHS improved coherence in it courses, increased opportunities in science, and moved to a more inquiry- and project-based instruction.

**STEM literacy.** The Programme for International Student Assessment (PISA) (OECD, 2006, 2009) has defined and assessed scientific literacy (Bybee et al., 2009). According to the OECD, scientific literacy includes the conceptual and procedural skills and abilities of individuals to address STEM-related personal, social, and global issues. Specifically STEM literacy involves the integration of STEM disciplines and these four components: a) using knowledge to identify issues, acquire new knowledge, and apply the knowledge to STEM-related

issues; b) The Nature of Science (NOS) understanding the characteristic features of STEM disciplines as forms of human endeavors that include the processes of inquiry, design, and analysis; c) recognizing how STEM disciplines shapes our material, intellectual, and cultural world; and d) engaging in STEM-related issues and with the ideas of STEM as concerned, effective, and constructive citizens (Bybee et al., 2009). Future citizens will need to be equipped with the knowledge and skills to apply scientific understanding to life situations involving science.

In addition to the content and skills that comprise STEM literacy, the MRHS science department wanted to graduate intellectually curious and scientifically interested students who appreciate and support scientific inquiry. Bybee et al. (2009) stated “attitudes toward science play an important role in scientific literacy. They underlie an individual’s interest in, attention to, and response to science and technology” (p. 869).

**Importance of coherence and connectedness.** In order for MRHS to graduate a greater number of scientifically literate graduates, the continuity of the overall curriculum had to be addressed; the traditional program lacked coherence. Cullen, Harris, and Hill (2012) stated, “curricular coherence, repeated experiences, and reflection on learning across courses are necessary” (p. 13). *A Framework for K-12 Science Education* (NRC, 2012) described the importance of the connection between courses and of the big ideas in science, suggesting that a multiyear sequence should be implemented to help students develop an increasingly sophisticated understanding. A coherent curriculum presents a complete set of interrelated ideas and makes the connections among them explicit (Kali, Linn, & Roseman, 2008). As students progress through school, their understanding of the connections among scientific ideas becomes

stronger and more sophisticated. MRHS structured revised and coherent curriculum in which the instruction and materials illustrate and model integrated understandings. MRHS worked to improve coherence for its target learners by mapping out the big ideas in a logical sequence and reordering the core courses, physics, chemistry, and biology (PCB). MRHS was beginning to consider inverting the traditional science sequence to a Physics First (PF), the PF-PCB model.

**The decision and implementation.** Over the course of two years, the MRHS science department investigated, considered, and debated many science programs. For example the department started by simply considering the addition of a new ninth-grade science course. Earth science and biology were the primary considerations. Soon thereafter, department members discussed changing the whole program from ninth to 12<sup>th</sup> grade, rather than simply plugging in a convenient ninth-grade course. The department considered throwing out all the old and bringing in something completely new. The goal was essentially to launch a new program concurrent with the opening of the new science building. Individual department members were tasked with researching and presenting potential programs to the group. Ultimately, the issue was decided by a departmental vote, along with the approval of the assistant principal for curriculum and scheduling (APCS). Conducting research, attending conferences, and soliciting the expertise of science education researchers were key to finding a good curricular fit.

The chair of the Department of Science Education at a nearby state university proved to be a significant resource for the MRHS science department. The professor had prior experience with a school on the East Coast that inverted its sequence to PF-PCB (physics–chemistry–biology [PCB]). She generously offered to help the department. She illustrated the potential benefits and challenges of implementing PF-PCB at MRHS. She attended a department meeting

where she guided a critical discussion of the PF-PCB program and quelled concerns by pointing to successful PF schools. She illustrated how to phase in a program, and she encouraged proper training. She also pointed the department to relevant research and recommended potential texts. The presence of a science education expert in department meetings was an important factor in the deliberation process. These meetings were professional and fruitful. They also coincided nicely with a science education conference that was coming to town.

In the spring of 2006, the MRHS science department had its gestalt moment. It marked the time when the collaborative thinking of the group became more cohesive and clear. After conducting research and consulting experts, the entire MRHS science department attended the NSTA national conference in Anaheim, CA. This was the first time the entire department had attended a national conference with the purpose of investigating and launching a new science program. Ten teachers divided responsibilities and searched for ideas and evidence that the department could use. For example, teachers attended sessions on PF led by the publishers, science education researchers, and the San Diego Unified School District (SDUSD), a recent adopter of PF. SDUSD presented data and shared challenges of their PF-PCB program, including their battle for acceptance by parents and the school district (Popkin, 2009; Taylor et al., 2005). This was MRHS's first encounter with resistance to the PF-PCB program. SDUSD presented mixed results. While physics enrollment and scores were on the rise, biology scores on the state standardized exam suffered. This underperformance was attributed to poor alignment of the state exams as the state test in biology is administered in the 10<sup>th</sup> grade; PF students do not take a life science until the 11<sup>th</sup> grade. Despite the eventual unpopularity of the program in SDUSD, the presentation was important to the MRHS discussion. At the same conference, Arthur Eisenkraft



presented his Active Physics program (Eisenkraft, 2005)--funded by National Science Foundation and specifically designed for PF schools--which addressed the deficiency of age-appropriate PF materials embedded with inquiry. The innovative book, along with Eisenkraft's approach to student learning, resonated with many department members. The NSTA conference provided the additional inspiration and courage to adopt the unique program. MRHS science teachers became convinced that PF-PCB was a good fit for their students, but obstacles remained.

The science department needed to convince the administration to invert the traditional curriculum and face the challenges that would follow; the easiest thing to do was not to change. The department decided it would be beneficial if they could identify a peer school where PF-PCB had been successfully implemented to serve as a model. Shortly after the NSTA conference the department found that school. To their surprise, this school had a PF-PCB science program for more than a decade, was on the West Coast, and was Catholic Jesuit, just like MRHS. This peer school became a PF school without much notice by the province. The department chair reasoned that the traditional sequence of biology first (biology--chemistry--physics) was simply an illogical order. She did not conduct extensive research or contact experts, but had recently attended graduate school for biochemistry and rationalized that modern biology required chemistry, and thus chemistry should be preceded by physics. Discovering a successful peer school that had decided to invert its sequence to PCB following similar reasoning helped convince MRHS administrators that the PF-PCB program was viable.

A serious question remained: Could ninth-grade students do "real" physics if sophisticated math is needed to do high school physics? MRHS's teachers investigated this

question by reviewing course topics outlined by state and national standards in addition to the College Board's SAT II physics subject test. After reviewing these materials a key endorsement came from MRHS's veteran AP Physics teacher. He determined that physics for ninth-grade students could be age-appropriate and effectively launched at MRHS if the topics were selected carefully and ordered appropriately with the algebra curriculum. The traditional senior curriculum could not simply be pushed down in to the ninth-grade year; age-appropriate materials needed to be created and adjusted for math. Work was begun to find course materials suited to ninth-grade physics.

After a year of research, discovery, and deliberation, the MRHS science department conducted a final vote in the spring of 2006 to determine which program they would adopt for the fall of 2007. Ten department members voted for PF-PCB and one voted for biology first (BCP). The dissenting vote came from a veteran physics teacher who was concerned that ninth-grade students could not perform the math needed to do sophisticated physics. The ballots were taken to the assistant principal for curriculum and supervision. The assistant principal, a former math teacher, made the decision: He granted approval in spite of his reservations. Given his experience in math and physics, he did not see how ninth-grade students could take physics; nevertheless, he asserted that he would not get in the way of a majority decision by a department. The administration at MRHS empowered and supported its teachers and authorized the change.

With the support of the administration, the science department used the final year (2006-2007) of the BCP sequence to plan for the transition to PF-PCB in fall 2007. The first major decision was whether to phase in incrementally or quickly. It was determined to do it all in one year. This meant that for one full year there would be no biology courses offered on campus as

the old program was phased out and the new one phased in: ninth-grade students were enrolled in physics and 10<sup>th</sup>- and 11<sup>th</sup>-grade students were enrolled in chemistry. This meant that biology teachers needed to teach physics or chemistry (Figure 1).

Figure 1  
*Science Courses Offered as MRHS Transitioned from BCP to PCB*

Grade	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011
9 <sup>th</sup>	No Science	Physics	Physics	Physics	Physics
10 <sup>th</sup>	<b>Bio</b>	<b>Chem</b>	Chem	Chem	Chem
11 <sup>th</sup>	Chem	<b>Chem</b>	<b>Bio</b>	Bio	Bio
12 <sup>th</sup>	Physics	Physics	<b>Physics</b>	<b>Physics</b>	AP/Electives

Biology teachers were eager and excited to be a part of change and to teach something new. They also were looking forward to developing a new biology curriculum for 11<sup>th</sup>-grade students that would build on a chemistry curriculum. Chemistry teachers also decided to change their approach to teaching chemistry. After learning that ninth-grade physics teachers would adopt a guided-inquiry, project-based, technology-rich physics program (Active Physics) (Eisenkraft, 2005), they decided to adopt the same program for chemistry (Active Chemistry) (Freebury & Eisenkraft, 2006). While this added to the challenge, it established the foundation for departmental transformation. The biology teachers soon followed suit by writing a curriculum that was based on the same principles. The entire department was affected by the PF decision; all the core courses—physics, chemistry, and biology—would never be the same again. Teachers agreed to embark on a complete transformation in curriculum, instruction, and assessment.

Empowered and invested teachers and administrative support were imperative to launching a new program, but training proved to be an essential component to implementation.

The MRHS science department conducted three major trainings in the year preceding the launch of the new PF-PCB program. During fall and spring finals, science teachers were relieved from exam proctoring duties to allow their participation in on-campus training. A highly recommended science educator presented a two-day workshop on guided inquiry teaching methods, project-based learning, and the application of the 5E and 7E model in ninth-grade physics (Bybee, 2009b; Eisenkraft, 2003). During the summer, the same trainer returned for a three-day workshop to help teachers plan and prepare for the fall-semester in physics and chemistry and implement inquiry methods and alternative assessments. While science teachers were unified and excited for this change, challenges lurked and skeptics remained.

After planning and training for inverting the curriculum from BCP to PF-PCB, the next challenge was to educate the community, particularly the parents and guidance (college) counselors. At open house (fall 2006) and during new student registration (spring 2007), the science department chair, teachers, and administrators educated the stakeholders about the program. The department believed that parents were initially struck by physics phobia, a common fear by a population where many have not taken a physics course or only took the applied math version of the course (Krauss, 2007). But after hearing that other families were registering their students for ninth-grade physics and that the course was designed for all ninth-grade students, many parents' fears were alleviated and they were more willing to experiment with the program. Many shared the rationale and excitement for transitioning to PF. By August 2007 nearly two-thirds (200) of the ninth-grade class were signed up for the physics course. After the semester began, many parents applauded PF; some cited their sons' excitement for and engagement in science. Still, some were not convinced that it was "real" physics or

complained that their students were frustrated with inquiry methods. These complaints came mostly from a small number of high-achieving students who felt uncomfortable with or lost in an inquiry-driven class. Students were unsure what they were supposed to know. They were expecting more direct instruction, lectures, problem-sets, and worksheets. Parents wanted to see their students succeed, but PF, guided-inquiry, and project-based learning was quite different from their previous experiences in science. Similar to parents, there were concerns expressed on MRHS's campus as well.

Counselors were unfamiliar with PF-PCB and were used to the traditional sequence of biology first (BCP). In the first two years of the program, at least two meetings per semester with the counseling staff and the science department chair were required to explain the rationale behind the program and to address concerns. Counselors were primarily concerned with how universities would view applicants that took physics in the ninth grade as opposed to the 12<sup>th</sup> grade. Many also felt that they should counsel their lower-achieving incoming ninth-grade students not to take the course since it was so rigorous in mathematics. The science chair reassured them that the course was designed for *all* incoming ninth-grade students, especially those that needed to strengthen their math skills. Also, they were pleased to know that the more sophisticated 12<sup>th</sup>-grade physics courses would remain in the curriculum for those that either chose not to take physics as ninth-grade students or those that wanted an AP courses in physics. While some resistance to change existed, over time counselors' concerns diminished as they came to understand the reasoning for the new sequence and were assured that the upper division physics courses would remain.

The science department decided that reordering the sequence of core courses was imperative to improve student learning and advance STEM literacy for all students. It was reasoned that ordering the big ideas in science in a logical manner would enable students to construct their learning over years to reflect a foundational and hierarchical approach to the scientific disciplines. Empowered MRHS science teachers developed a shared vision, conducted research, and collaboratively determined their goals in terms of content, skills, and attitudes (see tables at end of chapter). They decided that the core courses would be ninth-grade physics, 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology, i.e., a Physics First curriculum, and that the courses would be taught in using a guided-inquiry, project-based approach. This decision was informed by an investigation in to the history of science education in the United States and is reviewed in this chapter.

### **Curriculum and Sequencing: The *What* and *When* of Learning**

The MRHS science teachers determined that a physics first–biology last (PF-PCB) curriculum addressed the *what* and *when* of learning; PF-PCB provided the desired structure for *what* STEM literate graduates at MRHS should learn (skills and content goals) and *when* it was best learned. The PF-PCB curriculum targeted the big ideas and provided a scope and sequence that explicitly builds on and connects the core conceptual understandings. The logic behind the order and the promotion of deeper understandings challenged the department to investigate why the predominant order in the United States was biology first (biology–chemistry–physics (BCP)). The history and evolution of secondary science revealed the happenstance nature of the BCP (biology first–physics last) sequence and pushed the department to implement a scope and sequence that was based on student needs rather than tradition. The history of secondary science

education, particularly the order of courses, will be discussed further to justify the flipping of MRHS's curriculum.

### **Biology First Versus Physics First: Reasoning for Change**

MRHS science teachers grappled with the question: Could the majority of high schools in the United States be teaching science backwards at the cost of improved achievement? The current approach in secondary science education may not be optimized for student achievement and it may be time to consider a new approach. Modernizing curriculum in secondary science education in the 21<sup>st</sup> century is necessary for an effective democracy and vibrant economy. Students are underperforming in science and under-represented minority groups lack access.

The collective ability to understand, participate in, and meet the future's pressing scientific challenges in the arenas of public health and the environment requires a new level of scientific literacy, i.e. "civic scientific literacy" (Miller, 1998, p. 240) or "citizen science" literacy (Mueller et al., 2012, p. 2). A modern, democratic society requires scientifically knowledgeable citizens to function properly. DeBoer (2010) stated "Science as a way of thinking was more suitable for life in a democracy than the more authoritative methods offered by the classics and mathematics because the methods of science allowed individuals to be their own observers of the natural world and to draw conclusions independently based on those observations and the power of their own reasoning" (p. 281). A basic level of scientific literacy is necessary for informed decision-making and the process skills to address challenges. In addition, advancements in the STEM fields constitute a rapidly growing economic sector requiring a scientifically literate population. This leads one to question the efficacy of science education in the United States. Now is the time to more fully address the deficiencies the education system

has inherited and continues to perpetuate in secondary science. Modernizing science education may help address issues of national security and economic competitiveness, but more importantly, scientifically literate citizens will be better equipped to address STEM issues of the 21<sup>st</sup> century (Miller, 2004).

MRHS transformed its science program to meet the needs of its 21<sup>st</sup> century learners by implementing a PF-PCB program. PF-PCB places an algebra-based physics course at the beginning of the high school curriculum sequence to serve as the foundational course (ninth grade year) and is typically followed by chemistry and then biology (PCB). This is not the predominant curricular order. The majority of high schools across the United States offer biology first–physics last (BCP). Why the BCP sequence emerged as the dominant sequence provides important context to this discussion.

### **History of Science Education in the United States**

The predominant biology first (BCP) high school science sequence has roots established over 100 years ago and may need re-sequencing for the 21<sup>st</sup> century. Given advances in molecular biology, i.e., genetics and biochemistry, the placement of biology last in the high school curriculum after chemistry and physics is reasonable and should be examined (Sheppard, 2002, 2003). Biology has significantly changed over that time, especially in the last half of the century with discovery of the structure of DNA (Watson & Crick, 1953). The modern biology course includes a significant amount of cellular and molecular content in addition to older botanical and zoological topics. Given this progress, it becomes apparent that modern biology can be best learned with a foundation of chemistry and physics. Further, while contemporary biology presupposes knowledge of chemistry and physics, chemistry and physics do not require



an understanding of biology. The Biological Sciences Curriculum Study (BSCS) symposium published *Capstone Biology* (BSCS, 2006) demonstrating support for the reorganization of the high school curriculum by putting biology last. If science is hierarchical and if understanding new information requires a good conceptual understanding of previous material, then placing biology after physics and chemistry is justified. Cavanaugh (2006) found that modern biology requires an understanding of the behavior of molecules, and the study of molecules and atoms (i.e., chemistry content) is grounded in physics. The objection to this reasoning is that the high school physics requires higher mathematical skills and should be offered last when math skills are highest. Wilt (2005) asserted that, “chemistry actually uses more advanced mathematical concepts than physics” (p. 347) and “no pedagogical reason (specifically, lack of mathematical understanding) exists not to teach physics as a first year high school science course” (Wilt, 2005, p. 348). Thus, reordering the predominant biology first (BCP) secondary science curriculum by putting biology last and physics first (PCB) could improve student achievement in American high schools in the 21<sup>st</sup> century.

Influential physicist Leon Lederman championed Physics First (PF) by promoting that schools invert the traditional high school science sequence from BCP to PCB. Lederman formed the American Renaissance in Science Education (ARISE) project to promote and create PF resources (Bardeen & Lederman, 1998; Lederman, 1998, 2001, 2005). Lederman argued that PF-PCB was the logical order and a more efficient way of scaffolding science curriculum in high school in order to meet scientific literacy goals. He enthusiastically asserted that physics was conceptually appropriate as an introductory course and urged that age-appropriate materials and more effective methods be developed for ninth-grade physics courses.

Arthur Eisenkraft, former President of the NSTA (2000-2001), responded to Lederman's call by advocating for *Physics First, Physics for All* (Eisenkraft, 2010) and developed age-appropriate physics materials for PF schools called *Active Physics* funded by the National Science Foundation (NSF). Likewise, the American Association of Physics Teachers (AAPT) endorsed PF (2002, 2007) and a number of scientists, education researchers, and curriculum experts followed suit (Glasser, 2004; Hehn & Neuschatz, 2006; Neuschatz et al., 2008; Neuschatz & McFarling, 2003; Pasero, 2003; Wilt, 2005). They reasoned that physics was the foundational science and a necessary component of a three-year secondary science program. Furthermore, given the molecular nature of modern biology, chemistry was the central science, providing the knowledge and understandings needed for a richer understanding of biology.

In addition to providing a coherent curriculum, the proponents of PF championed the improved access to physics, especially for underrepresented minorities. Thus, Lederman's vision of a more equitable, learner-centered approach to teaching science is being realized as more secondary schools implement the PF curriculum. PF has been adopted by a number of schools; however, quantitative studies demonstrating improved achievement are lacking. By 2005 estimates showed that 4% of all U.S. high schools (3% public and 8% private schools) had implemented some variation of PF (Neuschatz et al., 2008). As more schools consider changes, there is a need by the science education community to study the PF-PCB programs at these schools quantitatively and in greater depth.

### **How students learn science and physics first**

In addition to the historical context, one must understand that MRHS's decision to change the sequence was influenced by the conceptual framework of constructivism as illustrated

in *How People Learn: Brain, Mind, Experience and School* (Bransford et al., 2000). Teachers were presented with the research found in this book during two professional development sessions a year before implementation. The book and its findings were discussed in subsequent monthly meetings. The theory of how students learn science entered informal conversations; it was often referenced when conferring and exchanging ideas regarding day-to-day teaching. This was the first time that learning theory directly informed the discussion. It forced teachers to reflect on their beliefs about learning and teaching. It challenged teachers to address their preconceptions of how students learn and to undo the misconceptions perpetuated by traditional methods. *How People Learn* illustrated that the sequence of learning mattered since students construct their learning over time. MRHS science department members came to the conclusion that, when seen through this constructivist lens, the predominant BCP is poorly sequenced and that a PCB sequence would serve the students better and enhance STEM literacy.

### **Significance of Change**

The lack of acceptable improvement in science education outcomes over the last three decades should compel educators to urgently seek and evaluate alternative curricular models, like PF. In *A Nation at Risk* (NCEE, 1983) the NCEE warned that American students are unprepared to participate in the rapidly evolving science and technology based workforce. TIMSS 2007 reported that U.S. 4<sup>th</sup>- and 8<sup>th</sup>-grade students continue to score well below their international counterparts in science (Gonzales et al., 2008). More recently the NCES reported in *The Nation's Report Card: Science 2009* that only 21% of 12<sup>th</sup>-grade students performed at or above proficient level in science and students of color, particularly from urban areas, performed

significantly lower on average (NCES, 2011). It is clear that something is not working and PF may be an alternative to the traditional paradigm.

Some educators believe that moving physics to the ninth grade corrects a century-old mistake, though the majority of science teachers who teach in the traditional BCP sequence oppose the change. Neuschatz, McFarling and White (2008) reported 70% of teachers participating in a PF-PCB program have positive opinions about it and that 80% of physics teachers think all students should take the course by the end of high school. Regardless, Neuschatz et al. (2008) reported that the majority of high school educators and researchers claimed that they would like to see physics remain the more sophisticated mathematical course. This reflected the view that physics is an applied math course and is driven by more advanced topics like geometry, trigonometry, and calculus. Neuschatz and McFarling (2003) concluded that a physics course incorporating this level of math should be placed in the 11<sup>th</sup> or 12<sup>th</sup> grades because it is too mathematically challenging for ninth-grade students. Others countered that physics should be defined as a science course rather than an applied math course: one that utilizes mathematics but is not driven by it (Wilt, 2005). Wilt (2005) summarized that “mathematics and conceptual perspectives provide no sufficient reason not to offer physics as a first science course (and) no reliable reason exists to believe that the concepts are beyond those students' [ninth-grade students] reach” (p. 351).

Hard data are needed to better inform the debate regarding the appropriateness and effectiveness of PF. Comprehensive and quantitative research is needed to move the conversation forward. Project ARISE reported that their most significant finding in a 2001 study of PF schools was “that schools are not quantitatively documenting the degree of their success”

(Pasero, 2003, p. 13). Neuschatz et al. (2008) found that while 4% of U.S. high schools have adopted PF and that the “only information about PF is anecdotal” (p. 26). In order to be considered a viable alternative PF curriculum needs to be evaluated more deeply and empirically in a quantitative fashion. MRHS provides an excellent opportunity to tell the story of change and to quantitatively evaluate student achievement in a PF-PCB program. Data used to evaluate the program are shared later in this chapter.

### **Instruction, Assessment, and Attitudes: The *How* and *Why* of Learning**

The previous section described how the MRHS science department addressed the *what* and *when* of student learning by researching and choosing a curriculum that constructed student learning and skills each year in high school: a Physics First (PF) curriculum. During the training sessions in the year prior to implementation of PF, it became clear to the science teachers that physics would be better taught using inquiry methods. They also determined that project-based learning with technology-rich inquiry instruction would enhance student learning and improve attitudes in science while offering an alternative way to assess students doing and applying science. Along with transitioning to a PF curriculum, the science faculty decided that student learning should be guided by inquiry-based methods—the *how* of learning—and should strive to improve student attitudes toward science through relevant questions and challenges—the *why* of student learning.

MRHS reformed *how* science was taught based on recent reforms, such as those recommended in *How Students Learn* and the National Science Education Standards by implementing inquiry-based, project-based, and technology-rich teaching practices (Donovan & Bransford, 2005; NRC, 2000). The biggest change in the curriculum delivery was the

introduction of guided inquiry. Guided-inquiry predominantly drives instruction in the core course at MRHS. This method was based on individual student's interests, strengths, experiences, and needs. It focused on student understanding and application of scientific knowledge, ideas, and inquiry processes. It guided students in active and extended scientific inquiries and it provides opportunities for scientific discussion and debate among students. It also effectively promoted what students should be able to do in science.

After the decision to embrace inquiry- and project-based learning, the MRHS science department sought out materials for the core curriculum (ninth-grade physics, 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology). Realizing that most textbooks were written in a way that did not support either inquiry- or project-based learning, the department considered eliminating the traditional, encyclopedic textbook and writing their own course readers where big questions would drive the learning and answers would be found in the students' heads rather than the back of the book. The effort to write, test and rewrite materials would have taken several years. Fortunately, the materials that supported this type of learning had already been developed. MRHS science teachers discovered new and innovative curricula: *Active Physics*, *Active Chemistry*, and *Insights in Biology* (Eisenkraft, 2005; Freebury & Eisenkraft, 2006; Miller, 2007).

*Active Physics* represents a new approach to teach physics and is certainly not a traditional textbook. The book fosters curiosity and discovery by incorporating both inquiry- and project-based learning. Each chapter in the book could stand alone as a unit and follows an enhanced version of the BSCS 5E model (Bybee, 2009b; Bybee et al., 2006; Eisenkraft, 2004). Chapters began with the presentation of a relevant project for the students known as a

“challenge.” The challenge was the assignment or project the students would complete by the end of the chapter. It drove the inquiry, which drove the learning and motivates the students. Students had a “need to know” the physics in order to address the challenge and present their own unique, creative project, that established relevance (the “why”). In addition to encouraging students’ natural curiosity and internal motivation to be creative, the challenge also offered an alternative end-of-chapter assessment.

For example, as part of the mechanics portion of the course, the MRHS teachers chose a challenge in *Active Physics* that required students to design a sport to be played on the moon. Physics teachers found this project engaging; the students were motivated to create something unique and relevant to their interests, i.e. a favorite sport. One lab group decided that “America’s pastime,” baseball, should be the first sport played on the moon. The students needed to determine the size of stadium. How far should the home run fence be? How high could a pop fly go and would it be easier to field? Would a curve ball work? Would the swing of a bat and the hitting of a ball feel the same? How would base running and sliding be different? All of these questions drove students to investigate the big concepts in physics, including projectile motion, velocity, acceleration, free fall, mass, gravity, energy, work, momentum, friction, air resistance, and so on. They wanted to know the answers to these questions so that they could design a proper moon-baseball stadium. In addition to engaging students with a problem that required creativity, the challenge served as a performance assessment. *Active Physics*, *Active Chemistry*, and *Insights in Biology* were innovative programs that utilized active learning, guided inquiry, and project-based learning to motivate students and enhance their learning by *doing*, *using*, and *discussing* science while providing alternative assessments.

The project-based learning (PBL) at MRHS in the *Active* and *Insights* programs advanced 21<sup>st</sup> century STEM education. It provides the opportunities for students to use core concepts, exercise the practices of science, be creative, apply and use science in the context of their world (Cullen et al., 2012). Creating, designing, and engineering solutions were now more than a one-time activity; they were embedded in the coursework. Technology continued the efforts to meet STEM goals. Students could quickly find, collect, organize, and display data electronically. More time could be spent on evaluating, analyzing, communicating and discussing data. Students could problem-solve, build models, and engineer solutions. PBL and inquiry-based methods address STEM education goals and improve attitudes and motivation.

MRHS strove to improve attitudes towards science and increase motivation in science by continually addressing the student question, “*Why* should I care?” Cullen et al. (2012) indicated that “[s]elf-directed learning is essential to the development of inquiry skills that individuals need in order to adapt to rapid changes in their environment and to manage the great influx of information to be learned” (p. 12). The MRHS core curriculum was selected and adapted to meet student needs. It was designed to respond to their interests, strengths, and experiences while capitalizing on their natural curiosity about how things work.

In a review of literature Osborne, Simon, and Collins (2003) highlighted the need to identify the aspects of teaching that make science engaging to students. They contended that the quality of teaching may be one of the most important factors in combating the decline in numbers of students choosing to study science. Carol Dweck informed this work by emphasizing the importance of intrinsic motivation and the *growth mindset* (Dweck, 2006). She stated, “great



teachers believe in the growth of intellect... and they are fascinated with the process of learning” (p. 194). This process fostered curiosity, motivation, and belief in oneself.

Addressing student motivation and attitudes reflected *A Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NRC, 2013). In *Taking Science to School* (2007), four strands of scientific proficiency were created that informed the *Framework*. Strand 4 of the *Framework* included effectively engaging students in science practices “for students’ motivation and attitudes toward science” (p. 252). At MRHS, improved student attitudes toward science and through practices may have been achieved. Since implementing the new PF-PCB program in 2007, student enrollment in science courses increased, which is a possible sign of improved attitudes and motivation to do more science.

### **Evaluation of the Physics First Program**

#### **Increased Enrollment**

By the time the first cohort (class of 2011) of PF students graduated from MRHS, the evidence revealed that the new program was serving more students better. Before the PF-PCB program approximately 80-90% of students graduated with three years of science with no more than 20% of those taking four years of science. Matteo Ricci’s addition a foundational science course for all ninth-grade students provided the opportunity for every student to take four years of science. Since implementing PF-PCB, more than 50% of MRHS students have graduated with four years of science. In addition, AP science course enrollment increased. Before the PF-PCB program, approximately 33% of a graduating class took at least one Advanced Placement science course (AP Biology, AP Environmental Science, AP Chemistry, AP Physics B or AP Physics C: Mechanics). After implementing the PF-PCB program at MRHS, more than 50% of the students

graduated with at least one AP science course. The PF-PCB program provided more access to science and, as a result, more students chose to take more science.

### **Data to Inform Instruction**

Following the implementation of PF, the MRHS science department used data to inform and improve instruction. Diagnostic exams were given to students enrolled in the new core courses (inquiry-based ninth-grade physics, 10<sup>th</sup>-grade chemistry, and 11<sup>th</sup>-grade biology) and the traditionally taught 12<sup>th</sup>-grade physics. Results demonstrated that ninth-grade physics students could do *real* physics and that the inquiry- and project-based learning could impressive results when compared to traditional methods of instruction, though at the expense of breadth of content.

**Evaluating ninth-grade physics.** In order to objectively evaluate student achievement in the ninth-grade physics course at MRHS, the science department administered two diagnostic exams to physics students: released test questions (RTQs) from the California Standards Test (CST) in Physics and the Force Concept Inventory (FCI).

The FCI was designed to assess student understanding of the most basic concepts of Newtonian mechanics (Hestenes et al., 1992). The questions focused on intuitive comprehension independent of terminology knowledge or numerical modeling. The FCI can be administered to students prior to introducing a mechanics unit to assess prior understanding and misconceptions as well as student learning and teaching effectiveness. The FCI was given to MRHS ninth-grade students in physics before and after the mechanics unit. The ninth-grade mean pre-score for first three years was 26.5% and the mean post-score was 50.7%. Over three years, ninth-grade students ( $n = 595$ ) in the *Active Physics* program averaged gains equaled 0.33. Hake (1998)

found that 11<sup>th</sup>- and 12<sup>th</sup>-grade physics courses that “made little or no use of interactive engagement (IE) methods achieved an average gain = 0.23” (p. 71). These results confirmed that ninth-grade physics students at MRHS using IE, i.e., *Active* methods, scored higher on the FCI than their 11<sup>th</sup>- and 12<sup>th</sup>-grade counterparts using traditional methods (1998). The FCI provided the first piece of evidence that ninth-grade physics at MRHS provided a real and profound experience with foundational physical concepts.

The department administered a second diagnostic test, the CST in physics. Annually, the California Department of Education (CDE) administered a standards-based high school science exam to students in public high schools in each of the four major content areas of science. Occasionally the CDE released examples of test questions. A copy of the released test questions (RTQs) from the CST in physics was used as an internal diagnostic to refine curriculum and instruction. The diagnostic exam also provided the opportunity to compare ninth- to 12<sup>th</sup>-grade physics at MRHS. Student scores in the guided-inquiry, project-based, i.e., *Active* or IE, ninth-grade course were compared to the 12<sup>th</sup>-grade course taught in a traditional manner. Students in the ninth grade (n = 595) physics course scored a 61.4% while the 12<sup>th</sup>-grade mean was 56.8% (n = 233). These scores confirm the FCI results: ninth-grade physics students at MRHS achieved results similar to their upper-grade counterparts and that *Active* (IE) instruction could play an important role in their learning.

The CST in physics could be broken down by content and skill area. The data showed that ninth-grade students outperformed their 12<sup>th</sup>-grade counterparts in the areas of investigation and experimentation, motion and forces, conservation of energy and momentum, waves, and electricity, but unperformed in the areas of heat and thermodynamics, and magnetism. These data

confirmed to the MRHS science teachers that active instruction was effective, particularly in the area of science practices, and that either teaching in the areas of heat, thermodynamics and magnetism needed improvement or sacrificing these topics was justified to make time for active instruction.

**Evaluating 10<sup>th</sup>-grade chemistry.** The science department used the RTQs from the CDE's CST in chemistry as an internal diagnostic to refine curriculum and instruction in chemistry. Ex post facto the CST in chemistry data provided the opportunity to compare 10<sup>th</sup>-grade students (n = 237) enrolled in the *Active Chemistry* (Freebury & Eisenkraft, 2006) program to their 11<sup>th</sup>-grade counterparts (n = 158) in the traditional course. Students (10<sup>th</sup> grade) in the *Active* program slightly outscored (52% to 48%) their 11<sup>th</sup>-grade counterparts.

The CST Chemistry diagnostic can be broken down by content and skill area. Like the CST Physics, the CST Chemistry data showed that the *Active* program yielded higher scores in the areas of investigation and experimentation, perhaps a result of more emphasis placed on these practices in those courses. The data also showed that 10<sup>th</sup>-grade students outperformed their 11<sup>th</sup>-grade counterparts in most areas, particularly in reaction rates and chemical equilibrium. These data informed teachers and spurred collaboration. Chemistry teachers refined activities and placed emphasis on the underperforming areas, like chemical equilibrium and conservation of matter and stoichiometry, and removed emphasis from nuclear processes in favor of *Active* instruction.

**Evaluating 11<sup>th</sup>-grade biology.** The CST Biology RTQs were used as an end-of-year diagnostic to evaluate the first two cohorts (2009-2010) of students in the new 11<sup>th</sup>-grade biology course. The data indicated a slight drop in performance from the first ( $M = 66.5\%$ ) to the second

cohort ( $M = 64.2\%$ ). The mean scores in the content areas of biology diagnostic were mixed. While investigation and experimentation scores improved, other areas dropped or remained relatively the same. Diagnostic data like these guided biology teachers to an important discussion of refinement: teachers modified the curriculum by placing more emphasis on cell biology, genetics, and evolution and removing physiology content in favor of guided-inquiry and project-based instruction, while increasing the emphasis on the nature of science and student practices.

### **A New Perspective: The *Framework* and NGSS**

The journey of change continued at MRHS and across the nation. The collaborative work of improving science education in the United States by refining standards and implementing best practices has been arduous and time-consuming. In 2012 the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and in early 2013, a promising draft of the *Next Generation Science Standards* (NGSS) (NRC, 2013) was released. These documents built on the decades of good work and progress. In 1990, Project 2061 published *Science for All Americans* (AAAS, 1990), which outlined what students should know and be able to do in science, mathematics and technology after 13 years of education. In 1996, the National Science Education Standards (NSES) emphasized inquiry-based teaching as “the central strategy for teaching science” (NRC, 2000, p. 173). Unfortunately this dominant theme of “scientific inquiry” may have taken a back seat to the vast number of facts and concepts outlined in the NSES. The *Framework* (NRC, 2012) and the NGSS (NRC, 2013) attempted to rectify this problem and MHRHS may be positioned well to adapt to the new standards.

The *Framework* (NRC, 2012) and NGSS (NRC, 2013) focused on core disciplinary ideas and concepts that apply across domains in science. This built coherence in the science

curriculum from year to year and explicitly outlines the optimal learning sequences or progressions that optimize deep student understanding. MRHS deliberately created a learning sequence that reflects the logical hierarchy of physics, chemistry, and biology. Students are able to build connections between these core disciplines from year to year. MRHS science teachers also used data to inform instruction and reduce the content of each course in favor of conceptual depth and skill development. Like the new national standards, core ideas and coherence across disciplines was valued.

In addition to sequencing the core ideas and creating coherence, the *Framework* (NRC, 2012) and NGSS (NRC, 2013) define more specifically the practices of science originally outlined by the NSES in 1996. More attention was now given to defining problems, asking questions, developing and using models, analyzing and interpreting data, arguing from evidence, and communicating results. This critical strand required teachers to create experiences where students obtained and communicated information, used mathematics and computational thinking, constructed explanations and design solutions. Students were asked to apply and use scientific knowledge rather than merely know about it. MRHS was well prepared to adopt these standards. Inquiry-methods require students to regularly engage in the practices of science; there was an emphasis on being able to *do* science. Additionally, project-based learning lent itself nicely to applying the engineering, design, and mathematical practices outlined by the *Framework* and NGSS. A coherent high school curriculum, like Physics First, that emphasized skills and attitudes and utilized inquiry-methods and projects that incorporate engineering, technology, and mathematics was on a path to meet the new NGSS and prepare STEM literate citizens for the 21<sup>st</sup> century. I argue that a program like this one also address the issue of social justice. The inclusive

nature of PF-PCB and differentiated instruction that is embedded in inquiry- and project-based learning removes many of the barriers that persist in the traditionally taught BCP sequence.

### **Social Justice: Science for All, Physics for All**

Arthur Eisenkraft (2010) stated “physics for all needs to include more than the limited group of white mathematically inclined men whom we have taught traditionally. Equal access to physics courses is one more step toward equal opportunities for all” (p. 328-9). If education in the US is for all, science should be for all, and physics should be for all. While this study of Physics First (PF-PCB) curriculum and inquiry- and project-based learning was informed by contemporary learning theory, it was also situated in social justice.

According to the ACT’s (2013) recent report on *The Condition of College and Career Readiness*, 31% of test takers in the United States met the College Readiness Benchmarks in science and 46% met the benchmarks in mathematics. African American graduates were least likely to meet the benchmarks, with only 7% meeting the science benchmark and 15% meeting the math benchmark. It was also reported that 16% of Hispanic/Latino test takers met the science benchmark and 13% met the math benchmark. Furthermore the College Board reported in *The Ninth Annual AP Report to the Nation* (2013) that access remained a concern. The data showed that among students with high potential for success in AP math course work, only 3 out of 10 Black/African American and Hispanic/Latino students took any such AP math course.

Minorities are the largest growing segment of the American population yet they are seriously underrepresented in STEM occupations. A 2011 report titled *Expanding Underrepresented Minority Participation: America’s Science and Technology Talent at the Crossroads* found that “in 2006 underrepresented minority groups represented 28.5% of our

national population but just 9.1% of college-educated Americans in science and engineering occupations” (NRC, 2011, p. 36). This report followed a two-decade-old report that urged secondary science curriculum and instruction to reform so that all students might have access. The American Association for the Advancement of Science (AAAS) published *Science for All Americans* (1990) and promoted a framework that would grant access to science education for all students. In *Science Education Leadership* DeBoer (2010) stated “[the AAAS report] recognized the value of science for all, not just for an elite few, and that science education should include knowledge about how science is done as well as scientific knowledge” (p. 301).

There are signs that the national minority gap in science and math education is slowly closing. Physics classrooms are becoming more diverse and more equitable results have been realized. Data showed that since the 1970s enrollment in physics courses has been gradually increasing from 20 to 30% (Hehn & Neuschatz, 2006). In terms of overall enrollment, female students have reached near parity and underrepresented minorities have made great strides towards closing the historical gap in physics-based course enrollment (Hehn & Neuschatz, 2006). For both Black/African American and Hispanic/Latino students, enrollment has increased from 1990 to 2005 from 10% each, to 23 and 24%, respectively (Neuschatz, McFarling & White, 2008). In a nationwide survey of high school physics teachers, the American Institute of Physics (White & Tesfaye, 2011) reported that “in 2009, about 25% of Black/African American and Hispanic/Latino high school students in the U.S. took at least one physics course prior to graduation. This is an increase from the 10% seen in 1990. However, the physics-taking rate for Blacks and Hispanics is still well below the 41% of White students and 52% of Asian students who will take at least one physics course in high school” (p. 1).



The increase in underrepresented groups in physics is promising. More inclusive programs, like Physics First, have helped narrow the gap; the sequence of courses naturally grants access to physics, which the other 70 to 75% of the population may not otherwise have. Placing physics first in high school curricula grants access to a science trajectory. In essence, offering physics to incoming high school students may create a school norm or culture that says all are capable of success in physics. It sends a message to incoming students and families about the value and importance of STEM classes. All students have to opportunity to take the most foundational discipline of the sciences, physics; and inquiry-based instruction is more inclusive.

In 1996, the NSES called for refining traditional science instruction by implementing more inquiry-based methods to address the needs of diverse learners. O'Brien and Thompson (2009) reported that in ninth-grade physics classes “the interactive method of instruction, and not the amount of traditional instruction, is the more important variable in student learning” (p. 237). Arthur Eisenkraft (2010) stated “We should develop teaching strategies that enable us to share an understanding of physics with all students because everyone deserves an opportunity to reflect on the wondrous workings of our universe” (p. 328). If teaching has the greatest impact on student learning (Darling-Hammond, 1997), then utilizing teaching methods grounded in contemporary learning theory provides the starting point of meeting needs of diverse learners.

In addition to sequencing course in a more inclusive manner, instructional methods need to be altered to provide more access to diverse learners. Kanter and Konstantopoulos (2010) reported that using culturally relevant pedagogical practices are important. They found that project-based learning (PBL) yielded higher achievement in underrepresented groups and that the frequency of inquiry-based activities correlated with student attitudes towards science.

Teaching physics using inquiry- and project-based methods acknowledges students' unique experiences, learning styles, and the reservoirs of knowledge they bring to the classroom.

Education is compulsory in the United States, and a mandatory three-year curriculum with physics as the foundational ninth-grade course, taught using inquiry- and project-based methods, would grant greater access to those that lack access to a coherent secondary science education. If the current two-year requirement does not change, the predominant curricular order remains biology first (BCP), and the dominant instructional methods continue in the traditional manner, then many underrepresented minorities will continue to lack access to higher levels of STEM education. Situated in this manner, MRHS's Physics First–Biology Last program can be viewed as promoting social justice.

It is now time to more fully embrace the vision shared decades ago by the American Association for the Advancement of Science (AAAS). In *Science For All Americans* (1990), the language used by the AAAS stressed both citizenship and personal development:

Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education - meaning education in science, mathematics, and technology - should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. America's future -its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities - depends more than ever on the character and quality of the education that the nation provides for all of its children. (AAAS 1990, p. xiii)

### **Conclusion**

Secondary science education is in need of modernization in order to enhance student learning, increase access, and prepare STEM-literate citizens to meet the demands and

challenges of the 21<sup>st</sup> century. The traditional methods of instruction and the predominant curricular sequence (BCP) need to be re-examined. Some schools have inverted the sequence in favor of a more coherent, logical PCB order, and have adopted more inquiry- and project-based teaching methods. The number of schools making this change has increased (Neuschatz et al., 2008), but more schools need to document "the degree of their success" (Pasero, 2003, p. 13). MRHS provided one story of change that created a learning environment that was "student centered, knowledge centered, assessment centered and community centered" (Bransford et al., 2000, p. 153).

Schools may want to follow MRHS's journey towards improvement. An empowered science department collaborated, researched, and created a new science program in an effort to produce STEM-literate graduates who are ready for college, careers and informed citizenship (see Appendices A, B, & C: MRHS's "Science Graduate at Graduation" objectives). The program addressed the *what*, *when*, *how*, and *why* of science learning by focusing on core content and practices; optimizing the learning sequence; implementing inquiry- and project-based methods; and improving attitudes and interest in science.

In conclusion, this chapter detailed Matteo Ricci High School's story of implementation and evaluation set in the context of the history of science education and current reforms. Reforming antiquated science curricula and instructional methods are vital for educators, administrators and researchers who care about advancing STEM education and scientific literacy for *all* students. From *A Nation at Risk* (NCEE, 1983), to the more recent NAEP (NCES, 2010, 2012) and TIMSS (Martin et al., 2012) reports, numerous studies have confirmed that U.S. 12<sup>th</sup>-grade students have scored well below their international counterparts. In order to advance

STEM education, Physics First, guided-inquiry and project-based learning should be considered a viable path to reform.

*Appendix A*

**The MRHS Science Graduate at Graduation: Content**

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**CONTENT**

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**What should a Matteo Ricci Science grad know and understand?**

1. Key language of Physics, Chemistry and Biology
2. Big Understandings
3. Basic Knowledge
4. Relevant facts
5. Key concepts
6. Important Models
7. Major theories and laws
8. Law vs Theories (laws are not proven theories)
9. Global cycles and systems
10. Matter and energy principles
11. Unity and diversity of life
12. Discoveries, Technology, Challenges, Issues, Impacts of Science
13. Energy and transformations
14. Light
15. Electricity
16. Classic mechanics
17. Matter
18. Quantum mechanics
19. Subatomic particles
20. Atoms, Molecules, Compounds
21. Physical & Chemical Changes
22. Energy flow & Matter cycling in living systems
23. Inheritance
24. Cells, Structure and Function
25. Evolution, Natural Selection
26. Ecosystems and Environmental Challenges (nature and man-made)
27. Energy sources for human use

*Appendix B*

**The MRHS Science Graduate at Graduation: Skills**

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**SKILLS**

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**What should a Matteo Ricci Science grad do?**

1. Question
2. Observe
3. Measure
4. Reasonably Predict
5. Classify
6. Analyze
7. Synthesize
8. Approach and set up a problem (experimental design)
9. Critically think
10. Collect, evaluate and organize quantitative data
11. Seek out evidence to support answer
12. Evaluate sources critically
13. Find and communicate error
14. Construct and defend argument using scientific evidence
15. Think abstractly
16. Decipher science from pseudo-science and articulate pseudo-religion (i.e., Intelligent Design)
17. Exercise objectivity and recognize bias, even their own
18. Be self-directed, follow their own curiosity and begin to find answers
19. Take action toward applying lessons learned outside the classroom
20. Exercise healthy skepticism
21. Evaluate statements empirically and changes views as facts change
22. Open to consider different points of view
23. See that science is full of interesting questions
24. See that science is enjoyable when questions that interest you are explored
25. Work collaboratively
26. Articulate science content, skills and values
27. Communicate questions and plan to answer them clearly
28. Do independent research
29. Develop a systematic approach to testing a problem
30. Transfer learning by recognizing opportunities to apply what they have learned
31. Use appropriate statistical tools intelligently to evaluate data
32. Filter out obvious bias, error & fallacious conclusions.
33. Communicate through a variety of media
34. Apply mathematics to determine patterns in nature or data

Appendix C

The MRHS Science Graduate at Graduation: Attitudes Towards the Nature of Science

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ATTITUDES & NOS

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Why should a Matteo Ricci Science grad care or appreciate science?

1. Science is something you *do*
2. Science is *a way* of knowing
3. Science helps explain yourself and your world
4. Science is relevant
5. Science applies to understanding and caring for human health
6. Science applies to understanding and being a steward of our world
7. Humans are a part of nature; no apart from nature
8. Misconceptions of Science persist and often pervade. You don't want to be fooled.
9. There is no single scientific method (rather the experimental method)
10. The NOS has is empirically-based and tentative
11. The NOS has is the product of observation and inference and creative thinking
12. The NOS has is subjective to a degree
13. The NOS does NOT produce absolute knowledge: (i.e., "Truth")
14. The NOS is influenced by social and cultural contexts
15. The NOS has strengths and limitations
16. In the NOS there are competing theories and answers
17. Faith and Science domains are often seen as conflicting, but actually may not.
18. Science can attempt to explain the "*how*" while religion can explain the "*why*"
19. We naturally curious and should enhance the natural sense of wonder
20. It is important to understanding what science is not
21. To see the connectedness of the world is enlightening
22. To see and appreciate common ancestry is enlightening
23. It is good to have a proper perspective of role of science to self and society
24. We are naturally "biophilic" and Science can nurture this connection to nature
25. Exploring the way the world works is FUN
26. Science at Matteo Ricci is for all
27. It is important to know what you don't know
28. There are no right answers in science, just approximations of right
29. The future depends on science and scientifically literate citizens
30. Our country can position itself to be a leader in science and problem solving

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