THE INFLUENCE OF THE PHYSICS FIRST COURSE SEQUENCE ON MISSOURI STUDENTS' BIOLOGY END OF COURSE ASSESSMENT

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By

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ABSTRACT

The purpose of this study was to determine if student performance on Missouri's Biology End of Course assessment is influenced by a Physics First curriculum sequence. Lederman (2001), the American Association of Physics Teachers (AAPT, 2002), and others have supported a revision of high school science course sequence from the traditional (biology-chemistry-physics) to one promoting Physics First (PF) for ninth grade students. In this sequence PF is followed by chemistry, and then biology. AAPT considers the sequence is more appropriate for learning the fundamental principles of the sciences, but there is a lack of empirical studies in the literature to provide evidence of its success. In Missouri, performance in science is only measured using the Biology End of Course (EOC) assessment where school proficiency data is reported as the percentage of students who score in the Proficient or Advanced levels. This research analyzed 2009-13 Biology EOC assessment results from 235 Missouri schools in order to determine the significant factors that predict proficiency. Independent variables included the assessment year (YR; 2009-13), grade level (GL; 9-11), science course sequence (SEQ; PF or other), and socioeconomic status (SES; % students enrolled in free or reduced lunch).

Hierarchical linear modeling was used to determine which of the four main effects and/or interactions contributed significantly to the model's fitness. Results showed YR and SES were the only significant predictors to assessment performance, and a reduced

linear model with only these two variables was not significantly different than the larger model with all variables and interactions included. This study has found the PF curriculum sequence does not produce significantly different biology scores than any other used by Missouri schools.

Chapter 1

Introduction

Prior to the 2008-2009 academic year, the state of Missouri assessed students by means of a comprehensive examination covering several areas of science. This Missouri Assessment Program (MAP) was originally established in response to the Outstanding Schools Act (1993). According to DESE (2013a) the Missouri State Board of Education directed DESE to develop and implement a comprehensive program to measure student proficiency in the knowledge, skills, and competencies in state content standards. As a result Missouri developed grade-level assessments for elementary, middle, and high school students in core academic content areas. The assessed areas for science included physical, life, and earth sciences as well as inquiry and relevance to society at the end of the 10th grade. This assessment was based upon the state standards known as Missouri's Grade Level Expectations (GLE's). These expectations were developed in response to the National Research Council's (NRC) *National Science Education Standards* (NRC, 1996) and were aligned with the format described in the American Association for the Advancement of Science's (AAAS) *Atlas of Science Literacy, Volume I* (AAAS, 2001). The final year for this assessment format occurred during the spring of 2007 when it moved to testing 11th grade students. During the 2007-08 academic year the state of Missouri implemented its revised assessment program to meet the requirements set forth by the No Child Left Behind (NCLB) act (NCLB, 2002). For high school students of science this meant that they would be assessed differently than had been done previously. Beginning with the 2008-09 academic year Missouri began assessing students completing a course in biology. The current Biology End of Course (EOC) assessment targets biology concepts associated with Missouri's Course Level Expectations (CLE's) as well as a performance event (PE) that measures abilities and understandings regarding inquiry. Since schools vary when they offer biology the assessment is appropriate regardless of grade level. During the summer prior to the start of the 2010-2011 academic year Missouri's Department of Elementary and Secondary Education (DESE) informed school districts that budget constraints would eliminate the PE and it would no longer be administered. Since this part of the assessment was hand-scored it was the most expensive part of the program. From the summer 2010 to the summer 2012 only biology content was assessed. The written PE returned during the 2012-2013 academic year.

With multiple science disciplines (biology, chemistry, physics, earth science, etc.) as part of most school curricula there leaves many options for when schools might choose to teach one particular course over another. The choice of high school science course sequence has roots as far back as the late 19th and early 20th century (DeBoer, 1991). At this time the choice of sequence was mainly driven by the perceived necessity for success in the universities. Although many versions of course sequence exist the primary, or traditional approach is the Biology–Chemistry–Physics (BCP) sequence (Sheppard & Robbins, 2009). The BCP approach has remained the predominant choice for schools in the United States; however, there have been many calls for restructuring the high school science sequence that differs from traditional high school sequences (Lederman, 2001; Bardeen, Freeman, Lederman, Marshall, Thompson, & Young, 1998; Bybee &Gardner, 2006).

After Nobel Laureate Leon Lederman, (2001) suggested a change to the current sequence, the American Association of Physics Teachers' (AAPT, 2002) published a position statement that supported the implementation of a curricular sequence for high school science that varied from the traditional BCP sequence. AAPT views high school science sequences should begin with a physics course in grade 9 followed by chemistry and then biology (PCB) in grade 11. This Physics First (PF) sequence was a new approach to the traditional BCP sequence that is prevalent in schools. The AAPT rationale for this PF sequence includes the following premises:

- Physics concepts are needed as prerequisites to understand chemistry and biology principles
- Physics is more concrete; whereas, biology is abstract
- Physics in ninth grade parallels the goals of basic algebra (solving equations, interpreting graphs, reasoning)
- PF has the 'potential' to provide a solid foundation and increase the coherency of the science curriculum

The Biological Sciences Curriculum Study (BSCS, 2006) in their *Cornerstone to Capstone* approach identifies various routes towards developing a PF approach. They agree that physics provides the basis for other science courses and encourage biology to become the "capstone" course within the high school sequence. DeHann (2005) suggests that if a PF curriculum is used for students entering college they will be more prepared for college science courses.

The University of Missouri in Columbia, Missouri has received two grants to support teachers and schools transitioning to a PF sequence. The first $3 million grant helped 72 ninth-grade science teachers from 25 school districts around the state implement PF program in their schools. It was sponsored by DESE as a mathematics-science partnership grant. When this program was launched Kostiuk (2007) reported a change in the sequence of science courses in many Missouri high schools that helped initiate PF. Toombs (2009) also reported that one of the principal investigators, Meera Chandrasekhar, had indicated an increase in their science and mathematics scores for schools that implemented PF.

The second $5 million grant was award by the National Science Foundation (NSF) (Grant# DUE 0928924). The project was funded to help increase student achievement in science by preparing 9th grade science teachers to teach a yearlong PF course. Professional development included physics content, pedagogy, research and evaluation (University of Missouri, 2013). A list of schools that have the designated PF sequence is available from *A TIME for Physics First* program's website where they indicate the initial phase of this program in 2010 included 37 school districts and added 18 in 2011.

In their most recent publication, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* the NRC (2012) provides a new direction for science education. It states the overarching goal of this new document is to provide a framework for how science education should

> . . .ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (p. 1)

However, they have recognized that the current state of science education in schools

> . . . fails to achieve these outcomes, in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done. (p. 1)

The challenge for schools is to create an appropriate high school science course sequence with efficient and effective curricula that can meet these demands, and help provide solutions to the existing dilemmas surrounding academic performance in the sciences.

Need for the Study

DESE (2013c) responded to the 1993 Outstanding Schools Act by adopting rigorous academic performance standards for students as they advanced through the public school system in Missouri. They believed these standards would better prepare their graduates for post-secondary education, the workplace, and civic responsibilities. In addition to the adoption of standards DESE developed and implemented a comprehensive assessment program in order to measure student proficiency in the knowledge, skills, and competencies for several content areas. Although the assessment program has evolved since its inception the pressure for accountability remains a key influence regarding important decisions that must be made on a regular basis by school leaders (Buxton & Provenzo, 2011).

DESE created the EOC assessments in order to meet state and federal requirements relating to NCLB (2002). The Missouri Biology EOC assessment is based on the state-developed standards specific to biology and was created in partnership with Missouri educators (DESE, 2012a). Since the expectations were written for high school students completing a biology course the assessment is appropriate for students at any high school grade level. As of 2013, the Biology EOC assessment is the only instrument used by DESE for assessing high school students in science; therefore, it is appropriate to the assessment as a basis of performance in biology.

There is limited research regarding the success of using the PF, or any other particular type of sequence, as a predictor of academic success in high school science. Even after Lederman's (2001) proposal to move to a specific PF sequence, BSCS (2006) has summarized American high school science courses as a "loosely organized smorgasbord…[with] relatively little structure or order to their [student] high school course selection" (p. 80). The Wall Street Journal (Tomsho, 2006) had reported that by 2011 over half of the states will require three science credits to graduate. Missouri is one state that adopted this requirement for graduating students beginning with the graduating class of 2010 (DESE, 2002). With this requirement, Missouri schools must work to determine which science courses they choose to offer and in what sequence. Given that several potential options exist it is important that Missouri school leaders have information based upon research regarding the factors that may result in increased EOC assessment performance. Whether one high school science course sequence is better than another for Missouri biology students is an important question that needs to be answered. The *Atlas* volumes (2001, 2007) show the order science concepts within a content area (biology, chemistry, physics, etc.) should be learned through grade spans, but does not suggest an appropriate sequence of learning where interconnections between content and within grade span areas are identified. This study addresses the research gap on the influence of science course sequence on student learning.

The purpose of this research was to determine whether a PF science course sequence in Missouri high schools results in better assessment performance on the Missouri Biology EOC than districts that utilize alternative sequences.

Operational Definitions

The following list includes the major terms associated with this study. Each term includes an operational definition that is used consistently within the study.

Academic (School) Year: Period of time from one summer to the next that includes EOC assessment data. The 2009-2010 academic year includes students who enroll in biology during the fall of 2009 and complete the EOC assessment during the spring 2010.

Achievement Level Descriptors (ALD): Student performance is reported in terms of four performance (or achievement) levels that describe a pathway to proficiency. Each achievement level represents standards of performance for each assessed content area; achievement levels describe what students can do in terms of the content and skills on the assessment. Panels comprised of Missouri educators and school administrators as well as post-secondary faculty and community business members play a role in determining achievement level cut scores. These scores are a means of comparing test results with standards of academic performance. For all content areas, a scale score of 200 to 224 is considered Proficient and a scale score of 225 and above is considered Advanced. (DESE, 2013c)

Adequate Yearly Progress (AYP): A state's measurement of performance based on assessment scores in the areas of language arts and mathematics. (NCLB, 2002)

Advanced:

> "Students performing at the Advanced level on the Missouri End-of-Course Assessment demonstrate a thorough understanding of the Course-Level Expectations for Biology. They demonstrate these skills in addition to understanding and applying the skills at the Proficient level; students scoring at the Advanced level use a range of strategies" (DESE, 2013c; p. 10).

Students earning Advanced status have a scaled score between 225-250.

American Association of Physics Teachers (AAPT): The largest professional association for physics teachers. The AAPT is active in supporting the dissemination of physics knowledge and excellence in physics teaching. (AAPT, 2009a)

Assessment Performance: The percentage of students whose final scores place them within one of four achievement levels (Below Basic, Basic, Proficient, Advanced). (DESE, 2011b; 2013b).

Assessment Years: The end date for an academic year's EOC assessment. Students completing the assessment in 2009 completed coursework in biology during the 2008-2009 academic year. Students completing the assessment in 2010 completed coursework in biology during the 2009-2010 academic year. Students completing the assessment in 2011 completed coursework in biology during the 2010-2011 academic year. Students completing the assessment in 2012 completed coursework in biology during the 2011-2012 academic year. Students completing the assessment in 2013 completed coursework in biology during the 2012-2013 academic year.

Below Basic:

> "Students performing at the Below Basic level on the Missouri End-of-Course Assessment demonstrate a limited understanding of the Course-Level Expectations for Biology. In addition to demonstrating these skills, students scoring at the Below Basic level use very few strategies and demonstrate a limited understanding of important Biological content and concepts" (DESE, 2013c; p. 10).

Students earning Below Basic status have a scaled score typically between 100-176.

Basic:

> "Students performing at the Basic level on the Missouri End-of-Course Assessment demonstrate a partial understanding of the Course-Level Expectations for Biology. They demonstrate these skills in addition to understanding and applying the skills at the Below Basic level; students scoring at the Basic level use some strategies" (DESE, 2013c; p. 10).

Students earning Basic status have a scaled score typically between 177-199.

Biology – Chemistry - Physics (BCP): Three year High School science course sequence that begins with Biology followed by Chemistry and then Physics. This is also known as the traditional science sequence.

Biology – Physics – Chemistry (BPC): Three year alternative high school science course sequence.

Chemistry – Physics – Biology (CPB): Three year alternative high school science course sequence.

Chemistry – Biology – Physics (CBP): Three year alternative high school science course sequence.

Course-Level Expectations (CLEs): Framework document for instruction and assessment in Biology. The CLEs include knowledge and performance goals of essential content, aligned to state and national documents that support inquiry-based instruction. (DESE, 2008b)

End of Course (EOC) Assessment: The state of Missouri's current testing format for high school students to help satisfy requirements for NCLB. After completing the coursework students take the EOC in Biology. (DESE, 2011b)

Free and Reduced Lunch (FRL): The percentage of students eligible for free or reduced price meals in schools. Families with incomes at or below 130% of the poverty level qualify for free meals). Families with incomes between 130-185% are eligible for reduced-price meals (Sirin, 2005)

Grade Level: High School grade in which the EOC in Biology is assessed (Grade 9, 10 or 11).

Highly Qualified Teacher: Teachers that hold a bachelor's degree, have full state certification or licensure, and have shown that they know each subject they teach. (NCLB, 2002)

High School: Schools that have students enrolled in grades 9-12.

Missouri Department of Elementary and Secondary Education (DESE): Administrative arm of Missouri's State Board of Education.

No Child Left Behind (NCLB) Act: Enacted in 2001, this federal law requires the implementation of standards-based reform and mandatory testing of certain basic skills at various grade levels. States are required to set their own proficiency levels and have assessments, measure progress, and report on their AYP regularly in order to receive federal funding. The act also requires states to provide highly qualified teachers for students in public schools. (NCLB, 2002)

Non Physics First (NPF): High school science curriculum sequence that does not begin with a first course in physics (e.g. BCP).

Physics First (PF): The curriculum and course sequence proposed by the AAPT that recommends a 9th grade conceptual Physics course for all students to prepare them for subsequent science courses. (AAPT, 2013).

Physics – Chemistry - Biology (PCB): Three year high school science course sequence typically recommended by supporters of the PF curricula. According to the American Institute of Physics data, 37% of public schools and 57% of private schools implementing PF use a full PCB sequence. (Popkin, 2009).

Physics – Biology – Chemistry (PBC): Three year alternative High School science course sequence that may or may not include PF curricula. Some schools may use a first course in physics that does not align with similar objectives to the PF program. Other schools may use physical science as their 9th grade course in science.

Proficient:

> "Students performing at the Proficient level on the Missouri End-of-Course Assessment demonstrate an understanding of the Course-Level Expectations for Biology. They demonstrate these skills in addition to understanding and applying the skills at the Basic level; students scoring at the Proficient level use a range of strategies." (DESE, 2013c; p. 10).

Students earning Proficient status have a scaled score typically between 200-224.

Proficient and Advanced (PA): The percentage of students who scored Proficient or Advanced on the Biology EOC in a given assessment year.

Reportable: The total number of students tested in a school whose Biology EOC scores are included in assessment performance.

Scaled Score:

> "A student receives an EOC scale score when he or she has a valid attempt in any test session. EOC scale scores range in value from 100 to 250. The EOC scale score determines the student's achievement level. For all content areas, a scale score of 200 to 224 is considered Proficient and a scale score of 225 and above is considered Advanced. Scale scores can be added, subtracted, and averaged." (DESE, 2013c)

School: A single school district that includes students in grades 9-12. Data provided by DESE used in this study represents the entire school district. A "School" may include one or more individual high school buildings. Data for each "School" included in this study represents all reportable scores for students who completed the Biology EOC assessment within the entire school district.

School Leaders: Individuals who are responsible for making, directing, and implementing decisions regarding curriculum, instruction, and assessment for a school.

These individuals may include superintendents, directors, principals, counselors, and/or teachers.

Socioeconomic Status (SES): Measurement based on the yearly percentage of students enrolled in the Federal Free and Reduced Lunch (FRL) program for students in each school completing the Biology EOC assessment.

Assumptions of the Study

Assumptions about the assessment. It is the responsibility of the state of Missouri to ensure the validity and reliability of the Biology EOC assessment it utilizes when assessing biology students. The various technical reports provided by DESE (2009, 2010, 2011b, 2012b, 2013a) provide the measurements of both and were assumed to be adequate for having the assessment measure high school biology students' performance. It was assumed that the assessment has remained consistent in its ability to measure performance in biology even if individual assessment items or structure of the assessment have changed. It was anticipated that some improvement in the assessment was likely to occur from the first to the most recent year of implementation since it is the goal of the assessment program to make continual improvements.

Assumptions about the sample. Biology EOC data reported by the state represents districts as a whole. Within this dataset this study recognizes there were likely students in many different grade levels and abilities completing biology the district indicated as a grade 9, 10, or 11 course in their sequence. For example, a district that offers biology in grade 10 may have students from grades 9, 11, or 12 enrolled (i.e.

students retaking the course or transfer students - a sophomore transfer may be enrolled in freshman biology). Although this is likely, the incidence of occurrence and influence on relevant conclusions was assumed to be minimal.

No distinctions were made regarding individual student abilities relative to completing the Biology EOC. Any school that administers the assessment was assumed to have similar student populations even though it is reasonable that varying abilities exist within each school. Any variations within the student sample may have the capability of increasing or decreasing the number of students reaching proficient or advanced on the Biology EOC. It is recognized that some low performing students who qualify for alternative testing complete an assessment (MAP-A: Missouri Assessment Program Alternative) that differs from the Biology EOC. MAP-A scores were not included in measures of biology assessment performance for this study.

It was also assumed that some performance data that was removed may have potentially increased or decreased outcomes. If a student's individual performance could not be determined even though they were eligible and accountable to assess, the results were returned as Level Not Determined (LND). It was recognized that LND results were not included in the final measurements for individual schools, but may have potentially influenced overall school or test group performance.

Assumptions related to sequencing and content. First, not all schools who offer Physics as the first course in their sequence may utilize an actual PF curriculum. A course sequence that began with a first course in physics but not actually identified as a PF course was placed within the NPF test groups for analysis of sequence differences and any results were assumed to be separate from actual PF schools.

Second, schools in PF test groups were assumed to be using different curriculum, textbooks, and teachers. This study does not attempt to determine whether one PF curriculum resource (textbook curriculum program, or teacher) was better than another even if one may exist.

Third, DESE (2008b) makes CLEs assessed on the Missouri Biology EOC versus those expectations assessed locally by schools. They state

> "The Science Course Level Expectations outline related ideas, concepts, skills and processes that form the foundation for understanding and learning science. . . . provides a framework to bring focus to teaching, learning, and assessing science . . . [and] outline[s] rigorous science expectations for students enrolled in traditional or integrated courses that will prepare them for success in college, the workplace, and effective participation in civic life." (p.1)

CLEs assessed on the Missouri Biology EOC are organized into the following areas: Characteristics and Interactions of Living Organisms, Changes in Ecosystems and Interactions of Organisms with their Environments, and Scientific Inquiry. As such, it was assumed students completing the Missouri Biology EOC for each assessment year had instruction and learning opportunities that included a minimum of the Missouri Biology EOC assessed CLEs, and did not receive any instruction relating to physics principles.

Limitations of the Study

Missouri mandates EOC testing in Biology to satisfy requirements of NCLB (2002). Since the Biology EOC assessment does not measure other content areas this study did not seek to determine how course sequence might influence proficiencies in other sciences. This study did not control what concepts were taught in each school in the sample, and was limited to outcomes related to student performance in biology. Measurements of assessment performance in the area of scientific inquiry for the years in which this data was available may reflect performance on a broader scale, but for this study it was included in the overall measurements of proficiency.

The Biology EOC results were only applicable to students in Missouri 1) who completed a biology course, 2) which each individual school deemed ready to test, and 3) only for the assessment years observed (2009-13). This study was limited in determining the influence on biology students' Biology EOC assessment performance within the state of Missouri and any subsequent outcomes were relative to each assessment year's population.

Each high school student is allowed to take the Missouri Biology EOC assessment once, so measurements of any progress within an individual school or group may be due to factors not measured by this study. This may have included but not limited to instructional methods and/or curricula, individual student abilities, and other school-specific characteristics that may have influenced outcomes.

Summary

This chapter has provided an overview of the need for investigating the role high school science course sequence may play in assessment performance for biology students. Advocates of the PCB sequence have made many claims regarding the purported outcomes that may result from implementing a PF sequence, but little data exists to support such claims. Since some schools in Missouri utilize the PF sequence it is important to validate these claims using available EOC assessment data provided by DESE. This study compares the PF sequence to other alternative sequences on how it influences performance on the Missouri Biology EOC.

The available literature on science course sequence and how it has influenced assessment performance as it relates to accountability is reviewed in Chapter 2. This chapter also provides a review of science concept connections, student performance, SES, and teacher quality in order to provide the basis for the literature gap. Chapter 3 reviews the structure of the research methodology including how the sample was selected, a description of the biology EOC assessment, the structure of the statistical model, and the format for data analysis. Chapter 4 reports the descriptive and inferential statistics in order to determine the factors that influences Missouri students' Biology EOC assessment performance. Finally, Chapter 5 (Summary of Study, Conclusions, Discussion, and Recommendations for Future Studies) discusses the implications from the research discoveries and makes recommendations for further studies that may be needed.

Chapter 2

Review of Literature

This chapter begins with an overview of accountability, teacher quality, and the history of the high school science sequence beginning with work by the Committee of Ten. It then presents a review of the proposed PF sequence recommended by the AAPT, the rationale for the PF sequence as it relates to science concepts, issues related to student performance, and SES.

Accountability

According to Atkin and Black (2003) legislative policy makers have been driven to produce legislation in the hopes of leveling international economic competitiveness, improving military strength, or decreasing the number of the unemployed. They acknowledge the role of schools being asked to carry out these reforms by making changes in curriculum and instruction for the sake of accountability. As such, school leaders have recognized the role accountability plays when it comes to decisions they make on a regular basis.

Many factors (cultural, systemic, and those internal to the teacher) influence curriculum in schools (Appleton, 2008), and one of the most influential has been the standards-based curricular movement (Oliver, 2008). The path for this movement was laid out in the third wave of systemic reform in the United States in order to achieve excellence and equity in education by the publications of standards by the National Council of Teachers of Mathematics (NCTM) in 1989 and AAAS publications in 1989 and 1993 (Kahle, 2008). This movement has resulted in large-scale assessments becoming the norm in today's school districts. Assessments (both formative and summative) provide important feedback to both the teacher and the student (Atkin & Black, 2003). This feedback is typically used to drive changes in curriculum, instruction, and/or learning. Literature reviews of large-scale assessment level in science education have become extensive and separate from those of assessments at the classroom level (Britton & Schneider, 2008).

Large-scale assessments and standardized testing dates back to the mid 1800's with Horace Mann and the Boston schools and are different from classroom assessments (Gallagher, 2003). Longo (2010) reports state legislatures have been using many types of large-scale assessments (such as the Third International Measure of Mathematics and Science, and the National Assessment of Educational Progress), for comparisons and guidance when evaluating their own assessments being used to gauge student performance and school improvement programs. With better results as a driving influence local school districts are competing for improved test scores by continuing to seek improvement in the ways teachers instruct and deliver a curriculum that is motivating, while at the same time properly aligned to state standards.

The pressure of accountability on large-scale assessment systems influences teaching practices and student learning in order to achieve performance goals (Britton & Schneider, 2008); consequently, the pressure on teachers and school-level administrators continues to increase (Buxton & Provenzo, 2011). According to Atkin and Black (2003) the largest impact from accountability influences appears to be how schools develop curriculum and how it affects what teachers do in the classroom. They noted important issues in designing and implementing a quality science curriculum is threatened due to the pressure for meeting the performance goals and content strands that are outlined in standards documents. It is not surprising that accountability pressures may lead less experienced elementary and middle grade science teachers who may lack science content knowledge to spend more time focusing on test preparation and less time on providing students the opportunity for experiences in authentic science (Abd-El-Khalick, Bell, & Lederman, 1998). Lee, Maerten-Rivera, Buxton, Penfield, and Secada (2009) found this was pronounced for teachers in urban school settings with more "at risk" student populations. Taylor, Jones, Broadwell, and Oppewal, (2008) reported 38 percent of 7 middle and 14 high school teachers surveyed emphasized their teaching focused mainly on improving test scores with little emphasis on inquiry, creativity, or individual teaching styles. They considered that the assessment accountability influences what they do in the classroom by sacrificing opportunities for in-depth inquiry investigations for test preparation. In a literature review by Donnelly and Sadler (2009) concluded the pressure of high-stakes testing and the accountability from the standards reform movement has typically landed on the shoulders of classroom teachers and has resulted in disturbing consequences relating to retaining quality teachers. Although a recent Gallup poll conducted by the Phi Delta Kappa (Bushaw & Calderon, 2014b) reported only 38% of Americans favor the use of standardized tests as a measure of teacher performance, research studies (Tye & O'Brien, 2002; Crocco & Costigan, 2007) have found accountability to high-stakes assessments has led to lower job satisfaction and increased the numbers of teachers leaving the profession.

The NCLB legislation (2002) that followed the standards-based movement driven by various science education entities has provided the impetus for the increase in state-level assessments (Donnelly & Sadler, 2009). Atkin and Black (2003) concluded large-scale assessments and the accountability that results must "simultaneously command the confidence of the public and also exert positive and helpful pressures on teachers and students" (p. 100), but it may often lead to test preparation practices in the classroom that can be counterproductive.

Bushaw and Calderon (2014a) reported 45% of Americans think that standardized tests are not helpful to teachers even though they support their use to evaluate student achievement. Missouri will continue to seek ways to improve the quality of education in its state. Section 105 of Title 5 of the Missouri Code of State Regulations (MO CSR) directs DESE Division of Learning Services and Office of Quality Schools to mandate a school improvement program that is currently in its 5th cycle of implementation and has the responsibility of reviewing and accrediting all public school districts in Missouri (MO CSR, 2012). As part of this regulation it establishes performance standards for academic achievement that are necessary for districts to achieve accreditation.

> 1) Student performance on assessments required by the MAP meets or exceeds the state standard or demonstrates improvement in performance over time, 2) The percent of students tested on each required MAP assessment meets or exceeds the state standard, (and) 3) Growth data indicate that students meet or exceed growth expectations. (DESE, 2013b; p. 6).

School districts will likely continue to seek solutions for continued improvement in order to meet local, state, and national demands set forth by policy. Accountability to these entities will necessitate appropriate curricular decisions of including not only what and how science topics are taught in the classroom, but also the sequence in which courses are offered.

Effective Physics Teachers and Teacher Quality

The U.S. Department of Education (DOE) has defined a "Highly Qualified Teacher" (HQT) in response to mandates required by NCLB. In their *"Fact Sheet: new no child left behind flexibility: highly qualified teachers"* (DOE, 2004) a HQT must have a bachelor's degree in the subject they teach with equivalent credits, full state certification or licensure with passage of a state-developed test, and prove that they know each subject they teach. The High, Objective, Uniform State Standard of Evaluation (HOUSSE) component of *NCLB* also allows states to develop additional ways for current teachers to meet highly qualified teacher requirements including teaching experience, professional development, advanced certification, or a graduate degree.

Prior to their introduction of the PF, AAPT (1988) provided a description as to the characteristics of a quality physics teacher. Cited in AAPT's (2009b) publication, "*The Role, Education, Qualifications, and Professional Development of Secondary School Physics Teachers"*

> Excellence in high school physics depends on many things: the teacher, course content, availability of apparatus for laboratory experiments, a clear philosophy and workable plan for meeting students' needs, serious dedication to learning goals, and adequate financial support. The role of the teacher, however, is the most important. Without a well-educated, strongly motivated, skilled, well-supported teacher, the arch of excellence in high school physics collapses. The teacher is the keystone of quality. (p. 9)

Since there is typically a high demand for science teachers, especially in the area of physics, the DOE (2004) has added flexibility for certification of science teachers as HQT. States may allow science teachers to demonstrate that they are highly qualified either in broad field science or individual fields of science (such as physics, biology or chemistry).

AAPT (2009a) has indicated that the number of physics teachers teaching PF will have to increase. They note additional teachers in other science content areas will have to be reassigned in order to meet the increase in demand for physics. Alderman (2008) reports non-physics teachers are teaching physics, and suggests this is a “bad thing”, and it is “not likely to change – ever”. A recent survey in 2012 (Banilower, 2013) indicated 23% of physics teachers have degrees in physics and 26% have not completed coursework beyond a single, introductory course. In Missouri, Frederick (1995) reported over 90% of the physics teachers did not have undergraduate physics degrees. In most states teachers are allowed to teach a part of their day outside their certificated area. This is where non-physics teachers teaching physics occurs. Aldermann (2008) also noted large schools will often have some physics classes taught by non-physics science teachers.

Physics teacher positions are the most difficult to fill in high schools (Hodapp, Hehn, & Hein, 2009). From 2002-2006, the 15 schools of education at the University of North Carolina graduated only three physics teachers**.** The Illinois Section of the American Association of Physics Teachers (ISAAPT) reported the number of openings for physics teachers for 2007 was estimated to be 56; however, the number of certified teachers graduating that year was estimated to only be between 9 and 12 (ISAAPT, 2004). Hodapp, et al. (2009) reported more than 23,000 United States high school physics teachers are not adequately prepared to teach the subject. He states only one-third of those who teach physics actually majored in physics or physics education, and physics majors today represent only about 1.4% of all graduates in science and mathematics. Missouri is one of five states with the greatest shortage of certified high school science teachers (ISAAPT, 2004), and from 2007-2011, Missouri universities averaged 5.6 new physics teachers per year (King, 2014). As a result of this lack of teachers in Missouri, teachers with mathematics certification can now teach PF courses (DESE, 2008a). This development may be inherently problematic. In AAPT's (2006) formal resolution they state "Physics First has the potential to foster greater scientific literacy and to help integrate physics, chemistry and biology syllabi" (p. 4).

If a physics class is being taught by a mathematics teacher who 1) is not required to have any prerequisite content knowledge mandated by state certification processes, and 2) lacks the effective pedagogical content knowledge for the effective teaching of physics, effective learning may be at risk. Banilower's (2013) study on the pedagogical preparedness of physics teachers reports 29% have spent less than six hours of professional development in the areas of effective science teaching in the last three years, in the last seven years 49% have not completed any coursework in science or the teaching of science, and 18% reported having never completed formal coursework in science teaching. Without formal training in the fundamentals of the nature of science, science processes, and effective pedagogy it may be doubtful to expect high schools in the state of Missouri to produce scientifically literate physics students.

AAPT also suggested PF is most effective when implemented by content-strong physics teachers (AAPT, 2009b). Okoye, Momoh, Aigbomian, and Okecha (2008) showed teacher quality had a positive significant relationship with achievement in science. However, in order to be effective and efficient, science teachers need to be well grounded in the subject matter, receive adequate professional training, accumulate experience, be resourceful, and participate actively in professional development activities. Lederman (2005) states, "…if we do it right…it will necessitate continuous and collegial professional development – ultimately occupying about 20% of teacher time (yes, expensive)" (p. 1). This is unfortunate considering Banilower (2013) reports physics teachers feeling less prepared to teach their subject area than other science teachers do in their subjects.

Atkin and Black (2003) believe that effective teachers are the key to successful science education programs. They believe that in order to be effective, teachers must be able to help students comprehend how the available evidence provides explanations for the major scientific concepts and principles within the content. They believe teachers must be able to establish an effective learning environment that promotes an understanding of scientific practices, and provides continual support for each student as they struggle with learning. In summary, they concluded curriculum and instructional materials are valuable, but the quality of teachers and their ability to be effective in their practice is paramount. Improving teacher quality should be the major goal of any science education reform.

Teacher quality is the most important factor for effective learning in any classroom (Strong, et al.2007; Bolyard & Moyer-Packenham, 2008). Raising teacher quality is a key instrument in improving student outcomes (Rockoff, 2004); however, efforts to improve science teacher quality in classrooms may be daunting because of the growing shortage of science teachers; especially in the area of physics education. A fundamental question remains; if schools are unable to fill the classrooms with quality, competent, effective, science teachers, how can they expect student success? The availability of these teachers to teach PF and subsequent physics electives in grades 10-12 may not be likely given the current state of teacher education programs and the number of eligible graduates in the field.

High School Science Sequences

In 1892 the National Education Association in Saratoga Springs, New York organized a committee to address concerns regarding consistencies in college entrance requirements. This committee consisted of ten different individuals who were charged with determining the proper limits within subject matter, the best methods of instruction, the amount of time spent in each subject area, and the best methods of assessment to ascertain proficiency. This group, later known as The Committee of Ten (CoT), developed a series of proposals that helped shape the foundation of course sequences thereafter (DeBoer, 1991).

The CoT Conference on Physics, Chemistry, and Astronomy had two opinions about the proper sequence of chemistry and physics. The majority opinion recommended that high school students receive a full course in chemistry prior to physics. Their rationale indicated that students would need additional time to master mathematical skills in order to comprehend the quantitative nature of physics while the minority opinion had the opposite recommendation. The minority indicated physics was a foundational science that would be needed for understanding the other science areas students were likely to study (Sheppard & Robbins, 2003).

The traditional BCP science course sequence in high schools remained prevalent and relatively unchanged since 1899 (Wilt, 2005), but questions regarding the specific science course sequence high school students should complete remained. Sheppard and Robbins (2003) analysis of the high school science course sequences noted key events that may have solidified the BCP sequence prevalent in high schools. They reported although the Committee on College Entrance Requirements in 1899 and the Dexter Report in 1906 both supported physics before chemistry, the Committee on the Reorganization of Science in Secondary Schools in 1920 supported a BCP sequence. This, along with the gradual trend placing physics last in the sequence from 1923-1930, essentially committed physics to an elective science credit rather than a requirement for all high school students. They concluded this trend was ultimately traced to declining enrollment in physics because "students found physics too abstract, too mathematical, too much like college courses, too geared toward examinations, too dependent on textbook learning, the labs were too formulaic and the teachers were inadequately prepared" (p. 422). This notion of mathematical proficiency as a necessity for physics has been seen as a common perception (Mervis, 1998).

DeBoer (1991) provides a glimpse into the historical development of physical sciences in secondary education. The need for a revised course in physics to improve enrollment was recognized in 1962 when the National Science Foundation began supporting new approaches to physics curricula. At this time the traditional structure of physics lacked the modern theories and broad unifying themes that evolved from the Sputnik era. Physical Science Study Committee (PSSC) was formed to help improve the state of physical science education. Accomplishments of this program included an introductory physical science textbook and laboratory guide with 51 experiments in 1963 and a full course published in 1967. Even with these improvements a 1977 national survey (Weiss, 1978) showed only 11% of school districts were using the PSSC materials.

Throughout the 1900's science education saw the gradual decline of physics enrollment contrary to the increase in biology and the stability of chemistry enrollments. DeBoer (1991) noted this decline was likely due to increased mathematics requirements, lack of relevance to everyday lives, and relating to criticisms of physics teaching.

Physics First

A 2012 national survey (Banilower, 2013) of 472 physics teachers indicated nearly all students (95%) in the United States have some access to a physics course; however, the number of available physics courses students have access accounts for only 14% of the total science curriculum. Although this is consistent from an earlier survey in 1990 (Neuschatz & Alpert, 1994) and an organized effort to improve teaching and curriculum, there has been little change in the placement of physics courses earlier in the secondary school sequence.

AAPT (2013) use 16 unpublished empirical studies as measurements of progress related to implementation of PF programs. A few of these include research on improved mathematics performance (Deakin, 2006; Glasser, 2004; Schuchardt, Malone, Diehl, Harless, Mcginnis, & Parr, 2008), improved scores in physics (Burgess, 2009; Bouma, 2010; Obrien & Thompson, 2009), and increased enrollment and interest in science courses (Goodman, 2006; Mountz, 2006; Vallette, 2007; Walker, 2008). Another study by Burgess (2010) compared scores from a chemistry final examination with 27 questions (n=52; 26 in each study group). Results showed that 10th grade students who had a physics-chemistry sequence scored significantly higher than those who participated in an integrated science-chemistry sequence (p=0.042). Burgess and Goff (2011) compared results on 25 multiple-choice questions consisting of items obtained from a released 2002 Advanced Placement examination. The results showed that grade 11 Advanced Placement Biology students who had participated in a PF sequence were slightly higher (though not significant) than grade 12 students from a different sequence.

Williams (2009) analyzed student performance data from four groups of subjects (n=346) who completed either BCP (honors or non-honors) or PCB (honors or non honors) sequences over three years (2007-2009). Data sources for performance included the ACT Explore, ACT Plan, ACT measures of College Readiness Standards, and the Illinois State Board of Education (ISBE)-Developed Science assessment. An independent samples t-Test was used to identify between-groups differences on the ISBE assessment.

Analysis indicated that there was no significant difference between the groups for each measure of academic performance in science or mathematics. There were significant results in measures of scientific reasoning gains (moderate effect size: η_p^2=.353) throughout the course sequence PCB students had greater gains in these measures than BCP students.

Ewald, Hickman, Hickman, and Myers (2005) reported "most schools have shown some improvement in science achievement and interest in science" (p 319) from PF implementations. Although they do not cite any empirical studies, they claim that students who have completed PF sequences during their high school education tend to 1) enroll and study more science, 2) have improved scores on standardized tests such as Advanced Placement (AP), Scholastic Aptitude Test II, and state examinations, and 3) have improved mathematics understanding and achievement. They also claim that PF programs are more balanced by gender and race, and result in increased student interest for science, technology, and engineering as a career.

More recently, Goodman and Etkina (2008) reported that a New Jersey PF program showed improved advanced placement science scores that were nearly 4.5 times higher than the state average. They also showed that interest in science increased yearly since the adoption of the PF program in 1999.

Obrien and Thompson (2009) compared Maine 9th grade PF students with 12th grade non-honors students enrolled in an elective physics course using a traditional lecture format. Their results showed 9th grade honors students significantly improved (35%) their scores regardless of instruction and were higher than the other students.

These results suggested that the student-centered approach, as provided by the PF curriculum, was better for 9th grade non-honors students (improved 18% compared to 3%). Regardless of instruction type 12th grade students performed better (23%) than 9th grade indicating that conceptual understanding is more likely attainable in upper grades even though all 12th grade students were non-honors and received traditional, lecture-based instruction. These results were interesting as they may suggest age may be the causal factor that results in better scores rather than one particular curriculum or the other.

More (2007) reports limited research has been done to demonstrate the effectiveness of PF sequence and whether school districts that adopted the program have seen any benefits. Popkin (2009) indicates the most significant setback to PF came as a result of the attempt by the San Diego school district. *Active Physics* (Eisenkraft, 2010) is the core program for *It's About Time* (IAT), and IAT indicates *Active Physics* is the only project based PF course (Eisenkraft, 2014). The Wall Street Journal (Tomsho, 2006) reported the science curriculum sequence (PCB) in the San Diego school district that includes the *Active Physics* text and curriculum program has done little to raise test scores. They also reported only 2% of Hispanic and African American students scored at proficient or advanced levels on the California state physics test compared to 10% overall. To culminate their results they reported nearly two-thirds of students continue to score in the below-basic range. The San Diego school district stopped requiring ninth grade physics in 2006 although 20 of 27 schools offered physics to some ninth grade students (Popkin, 2009). Currently the San Diego school system offers two introductory physics courses; both of which require Algebra 1 and 2. One of the courses is cited as being more “rigorous and mathematically demanding” (p. 13) than the other which uses a textbook that is not associated with the Active Physics curriculum although it is conceptually based (San Diego Unified School District, 2013).

There may be some disagreement between the type of PF curricula that should be implemented. Lederman (2005) recommends the “conceptual physics” approach; whereas, Goodman and Etkina (2005) provide evidence that a PF course rooted in algebra is more appropriate. Frederick (1995) reported an increase in physics courses that utilized the conceptual approach. Dreon’s (2006) survey of twelve PF schools in Pennsylvania showed many differences in PF programs including the text being used (where eight used the same) and curricular materials, but no information was provided regarding the depth or breadth of specific physics topics being taught. This may provide a source of error when comparing similar districts within Dreon’s study. The study additionally did not seek to determine whether one PF sequence was better than the other.

In 2009 AAPT reported that PF schools have indicated implementation of PF programs being “successful” (AAPT, 2009a). They indicate that teachers are satisfied with the program and that students are generally interested in the curriculum. However, in order to fully recognize the success of this program more data is needed in regards to actual student performance. The gap in this literature remains that research comparing chemistry and/or biology scores between different sequences is needed.

Learning Transfer

All new learning involves some sort of transfer of knowledge from what was previously learned. According to *"How People Learn"* (Bransford, Brown, & Cocking, 1999) learning transfer theory proposes that learned content may be able to be applied into new and often contrasting problems and context. However, several aspects of learning may affect the ability to transfer what has been learned into a new situation. They suggest there are several factors (quantity, quality, context, preconceptions, metacognition) that may influence the ability to transfer knowledge. The transfer of what is learned in a school setting to life beyond its walls is the ultimate purpose of school-based learning. It becomes important for educators to reconsider how a subject is taught and how students may learn in order to achieve success in post secondary experiences.

The ability of one high school course to influence success in another may rest in the ability of the student to transfer certain aspects of learned material from course to course. Science is known to have interconnected concepts (AAAS, 2001; 2007) and many unifying themes (scientific practices, energy transfer, continuity and change, structure and function, etc.; NRC, 1996). This ability to apply interconnected ideas within the various scientific disciplines may improve the ability to reason scientifically, and therefore manifest itself in improved success in other science courses. Some studies have shown that improved scientific reasoning and process skills may be a predictor of student performance in both introductory college level biology (Johnson & Lawson, 1998) and physics (Tfeily & Dancy, 2007).

Sadler and Tai (2007) studied the impact of high school science and mathematics courses on success in introductory college courses. In their research that included over 8500 students at 63 colleges and universities they reported content-specific courses resulted in improved scores but had no impact across disciplines. Students who completed high school physics did better in college physics but not necessarily in college biology or chemistry. They also found more mathematics courses completed in high school resulted in overall improved scores in college science classes.

Science Concepts

Goodman and Etkina (2008) consider the PCB sequence "logical" (p 222) because a physics background is necessary to understand chemistry and both chemistry and physics are needed for learning biology. Two of the most important documents recently developed in science education were produced by the AAAS Project 2061; *Atlas of Science Literacy: Volumes I and II* (AAAS, 2001; 2007). The *Atlas*, developed from *Benchmarks for Science Literacy* (AAAS, 1993)*, Science for All Americans* (AAAS, 1989)*,* and the *National Science Education Standards*, (NRC, 1996) shows specific learning goals and content connections between areas of science and mathematics using concept (strand) maps. Each strand map within the *Atlas* volumes is designed to help the reader find ideas or skills that develop over time and how they are interconnected with other strands or benchmarks. This way, educators can make sense of grade-to-grade as well as content-to-content connections. However, the list provided by AAPT (2009) indicates only two of 17 topics are related to biology (energy, atomic structure) even when most PF schools list only “energy” as a related topic. Additionally, a review of the two *Atlas* volumes shows the following results:

Volume I:

- “Laws of Motion” and “Waves” strand maps show no connection to chemistry or biology
- “Heredity”, “Cell Functions”, “Cells and Organs”, “Flow of Matter and Energy”, “Flow of Energy in Ecosystems”, “Biological Evolution”, “Natural Selection”, and “Behavior” strand maps show no connections from 9-12 physics-related maps.
- “Cell Functions” strand map shows connections from “Chemical Reactions”, “Atoms and Molecules” (chemistry-related maps)
- “Natural Selection” strand map shows connections from “Change’s in the Earth’s Surface” (earth science strand map) with connections from “Atoms and Molecules” and “Conservation of Matter” strand maps.

Volume II:

- “Diversity of Life”, “Interdependence of Life” and “Human Organism” maps show no connections from 9-12 physics maps
- “Energy Transformations” and “Electricity and Magnetism” maps show no 9-12 connections to biology-related maps

The lack of content connections between science courses in a PCB sequence refute arguments by Goodman and Etkina (2008) who suggested physics content is necessary for subsequent connections to significant amounts of concepts in biology. Tsaparlis (1997) noted students are less likely to understand new concepts if attempts to connect related concepts that are not well understood are made. However, the strand maps do suggest that concept connections are essential from one grade level to the next. Strong connections demonstrated by the *Axis'* maps are scaffolded (increasing depth of understanding with teacher support) within specific contents. This may indicate that in order for essential understanding to occur for any content area, related concepts should be presented in a progressive manner. Increasing the depth of understanding by revisiting the same concepts from early grade levels to later ones may provide the framework for more efficient learning of difficult, but important science concepts. This does not suggest that the conceptual understanding of one science content would not benefit or be corrupted from a PCB sequence. The argument is whether the position of the AAPT is valid in regards to physics content being necessary for understanding in chemistry and biology through interconnections or scaffolding. Finally, there are some that question AAPT's assertion that biology concepts are more abstract (AAPT, 2002) which would justify a PF approach that is more grounded in concrete concepts easier for conceptual understanding. Duit, Niedderer, and Schecker's (2008) review of physics teaching research noted a distinguishing feature of physics from other sciences is its "extremely high level of abstraction and idealization" (p. 605). These conflicting views may do little to assist schools seeking to determine the best science course sequence for learning science content if one exists.

Socioeconomic Status

Science for all Americans (AAAS, 1989) painted a vision for the future where all Americans would receive a comprehensive science education in preparation for the 21st Century. Although traditional science instruction assumed students had access to certain educational resources at home (Okhee & Luykx, 2007), standardized measures of achievement have indicated significant gaps among students of different SES backgrounds. Okhee and Luykx (2007) noted disparities remain in nearly all measures of science achievement. They attribute the lack of measurable improvements in science education is due to the absence of available research, thus restricting the ability of researchers to gain insight into the differences in achievement. As the focus on the performance of disaggregated groups began to increase after *Science for Americans* (AAAS, 1989), the role of SES on achievement became apparent when large-scale assessment results indicated FRL students were performing well below those who were not FRL eligible (O'Sullivan, Lauko, Grigg, Quian, & Zhang, 2003). Analysis of the National Assessment of Educational Progress (NAEP), National Education Longitudinal Study (NELS), American College Test (ACT), Scholastic Aptitude Test (SAT), and Advanced Placement Exams (AP) revealed patterns of achievement gaps across the various assessments in relation to SES and other minority groups (Rodriguez, 1998). Sirin (2005) suggests there is likely a connection between lower SES and underperforming minority groups because both are more apt to live in low-income households or in single parent families, have parents with less education, and often attend under-funded schools. This may indicate a connection between these factors as components of SES and thereby linked to academic achievement.

Sirin (2005) noted parental income (the main basis for enrollment in FRL) reflects the potential for social and economic resources available to the student; therefore, enrollment in FRL is a good indicator of SES. According to the United States Department of Education Office of Planning, Evaluation and Policy Development, Performance Information Management Service (2012), the eligibility for FRL is set yearly by the U. S. Secretary of Agriculture and is determined primarily by household size and income measures. Eligible households with incomes at or below 130 percent of the federal poverty level meet eligibility for free meals, and households with incomes between 130 and 185 percent are eligible for reduced-price meals. For example, the United States Department of Agriculture (USDA) 2012-2013 academic year eligibility standards indicates households of four persons would be eligible for free lunch if their annual income is no more than $29,965, and for reduced-price lunch if the family’s income does not exceed $42,643 (USDA, 2012). A student’s eligibility for FRL is established through self-reporting of family size and income (usually an application sent home for the family to complete and return to the school), or evidence of some categorical eligibility (i.e. students who already receive assistance through other programs).

Sirin (2005) performed a meta-analysis on the influence of SES on academic achievement. This research analyzed 74 independent studies between 1990 and 2000 resulting in an analysis of 101,157 students in 6,871 schools, and 128 school districts. The results from this review indicated the magnitude of the relationship between SES and academic achievement is contingent upon several complex and interwoven factors (type of SES measure, grade level, minority status, and school location). SES was found to be a stronger predictor of academic achievement for white students than other minority students, and the relationship between family SES and academic achievement was weakest for urban schools as compared with non-urban schools. Finally, the magnitude of the relationship between SES and achievement increased significantly through each grade level suggesting not only do gaps exist, but they can also widen over time.

Bower (2011) noted non-school factors (health and health care, housing and neighborhoods, economic well-being, and family) contribute more to and can predict the achievement gap between different classes compared to in-school factors and suggests if various non-school conditions and factors were altered it might help those who tend to score the lowest and help close this gap. A study in Australia by the Organisation for Economic Co-operation and Development (2007) found measures of the parents' occupational status, educational attainment, wealth, or other educational and cultural items accounted for an 11.3% gap in student science achievement. Peng and Hill (1994) reported clear evidence more parental involvement in their child's education by providing supervision of homework and access to supplementary reading materials produces greater science achievement. They also noted the parents' educational background is influential in producing increased attitudes and career aspirations in the sciences. However, Bower (2011) states "we know that students with more educated parents tend to do better in school, but it is less clear that children would subsequently perform better if their parents received more education" (p. 23). White (1982), and Singleton and Linton (2006) suggests characteristics of the family, rather than SES, are correlated with academic achievement. Therefore, it may be important to focus on parental roles in the educational success of their children regardless of their SES. Smith and Hausafus (1998) reported when lower SES parents who lacked science and mathematics backgrounds communicated and enforced high expectations for performance, achievement scores for their children were greater than those of the same SES whose parents were less involved.

Summary

This chapter has revealed a distinct gap in the literature regarding the influence of high school science course sequencing for Missouri schools. If other states utilize a similar EOC assessment in one particular content area, then the issue remains for curriculum and instructional leaders in schools. What sequence should students complete in order to best perform on high-stakes tests?

The chapter began by discussing the role accountability has played in regards to how large-scale assessments influence school, curriculum, and classroom-level decisions. These decisions lay the foundation for what will actually take place in the classroom; therefore, research relating to HQT followed. Next, the chapter summarized the history of the high school science sequence beginning with work by the Committee of Ten and culminating in the rational for the proposed PF sequence recommended by AAPT. AAPT advocates replacing the traditional BCP sequence in favor of the PF sequence claiming it addresses issues relating to the alignment of content between courses. They suggest a first course in physics provides a solid foundation for future learning in subsequent high school science courses including chemistry and biology. However, after the review of many studies cited by AAPT, long-term, large-scale, empirical studies that support a PF approach are still lacking. This chapter provided an analysis of the absence of content connections between physics and biology and a summary of the literature relating to the transfer of learning. Finally, the literature review on SES has revealed the dilemmas surrounding quality, educational opportunities in science for all Americans. The complex social and economic nature how levels of SES are defined has necessitated increased studies that may shed light on the causes of achievement gaps that are known to exist between the different classes of SES as well as uncover the barriers lower SES levels create for optimal learning and achievement in science.

Chapter 3

Method

This chapter describes the methods used in the study to answer the research questions. The structure of the independent variables and their potential influence on the dependent variable is discussed, as well as the ways in which each question was analyzed is described. A review of the assessment instrument is provided as it provides the basis for how the percentage of students scoring Proficient or Advanced (PA) was used for the dependent variable. Next, the process for selecting schools and the standards used to place them into the sample's test groups are described. Collectively, these methods show how the study worked to minimize error by reducing the extraneous variables likely to influence the results. The statistical analysis follows revealing the structure of the 2-level statistical model used to incorporate the main effects and their interactions as predictors for assessment performance. Finally, the method summarizes the hierarchical linear modeling approach that was used to simplify the 2-level model into simpler models that provided the basis for determining whether or not each hypothesis would be rejected.

Research Questions

The overarching goal that guides the methodology in this investigation was to determine whether or not specific high school science course sequences in high school produce significantly better performance on Missouri's Biology EOC assessment. The experimental design included four main effects variables: assessment year (YR: 2009-13), high school grade level (GL: 9-11) in which the assessment was primarily administered within a school, high school science course sequence (SEQ), and socioeconomic status (SES) as measured by the percentage of students enrolled in the Federal Free and Reduced Lunch (FRL) program. Since the PF science sequence has been recommended, schools that used the PF sequence were identified as the group for comparison to all other Non Physics First (NPF) sequences. PA was used as the dependent variable since these students were considered to have met acceptable performance levels in science required by DESE (2013c).

The following research question were addressed this study:

1. Is there a significant relationship between high school grades 9-11 and assessment performance (PA) on the Missouri Biology EOC?
2. Is there a significant difference in PA between high school course sequences on the Missouri Biology EOC?
3. Is there a significant difference in PA between assessment years 2009-2013 on the Missouri Biology EOC?
4. Is there a significant relationship between PA and SES as measured by FRL in a school and the Missouri Biology EOC?
5. Does the SES as measured by the FRL in a school influence any assessment performance trends from 2009-13?

The hypotheses are presented later in this chapter within the Statistical Analysis section.

Data Analysis

Question 1 included the grade level main effect variable and a between schools variable for the statistical model. The grade level was compared to average PA in order to determine if one grade level performed statistically better than the others. Data analysis only included schools that indicated the primary grade level in which the biology assessment was administered stayed consistent from 2009-13.

Question 2 focused on the course sequence (SEQ) variable from the statistical model. The analysis of the course sequence is the focal point of this investigation and was a between-schools variable. As the PF course sequence is recommended, it was used as the sequence by which all other high school science course sequences were compared. Schools included in this study maintained the same curricular sequence from 2009-13.

Question 3 was asked in order to determine if any differences exist between the different years the assessment has been administered. This main effect, within schools variable was analyzed in order to reveal differences within the EOC itself from year to year as the EOC assessment items may have changed during the life of the assessment. Each assessment year included selected response questions designed to assess biology content knowledge, but some academic years (2010-2011, and 2011-2012) did not include a written performance event (PE) section where elements of scientific inquiry were assessed. Schools that were included in this study had data from all five assessment years (2009-13).

Question 4 (SES) was the final main effect variables nested within schools for each grade level in which the assessment was completed. This disaggregated data was chosen in order to provide a characteristic of the student population within each school.

Question 5 arose at the end of data analysis as patterns began to emerge within the data. Upon discovery of specific causal factors for assessment performance it was questioned whether this specific interaction between SES and YR might provide a unique predictor.

Instrumentation: Biology End of Course Assessment

The EOC assessments meet state and federal requirements relating to NCLB (2002). The Missouri Biology EOC assessment is based on the state-developed standards known as the Course-Level Expectations (CLEs; Appendix A) and was created in partnership with Missouri educators (DESE, 2012a). DESE (2008) explicitly differentiates Biology CLEs assessed on the Missouri Biology EOC compared to those intended to be assessed locally. DESE (2008) states "[An] * indicates that an item is essential to the curricula of the Course but will not be assessed at the State level. The indicated expectations should be taught and assessed locally" (p. i). The assessment is appropriate for any student who has successfully completed a high school biology course regardless which grade level the student completed the coursework. Individual school districts are responsible for determining if a student is ready for the EOC. This typically occurs in the spring of the normal academic year; however, some students may complete the course in the summer or fall. Currently, the Biology EOC assessment was the only instrument used by DESE for assessing high school students in science.

Format. The assessment was originally designed with two sessions. Session one is the selected response (multiple choice) component. This section's minimum and maximum percent content included the following assessed strands: Characteristics and Interactions of Living Organisms (36-44%), Changes in Ecosystems and Interactions of Organisms with their Environments (22-27%). Session two is the PE section that includes a series of connected constructed response tasks that assesses elements of Scientific Inquiry (36%). For academic years that did not include the PE (2010-11 and 2011-2012) the percent content on the assessment was adjusted (Characteristics and Interactions of

Living Organisms: 63%; Changes in Ecosystems and Interactions of Organisms with their Environments: 37%) (DESE, 2010). The assessment does not have a time limit; however, there are reasonable recommendations for schools (DESE, 2012a). The selected response session is recommended to take between 55-60 minutes, and for the academic years in which there was a PE (2008-09, 2009-2010, and 2012-13) this session typically requires 65-70 minutes. The assessment is available for most students through an online platform, but accommodations are available for students with special needs (paper/pencil, large print, Braille).

Reliability. DESE defines reliability as "the consistency of student test scores" in each assessment year's technical reports documents (DESE, 2009; 2010; 2011b; 2012b; 2013a) and provides details of the reliability estimation techniques. Internal consistency reliability coefficients, conditional standard errors of measurement and inter-rater reliability for the scoring of the PE are all included in these reports.

Reliability of the Biology EOC assessments is evaluated using Cronbach's (1951) coefficient alpha. DESE considers reliability coefficients ≥ 0.8 to be acceptable (DESE, 2012b). Cronbach's alpha reliability measures for this assessment were obtained for from the yearly technical reports provided by DESE (2009, 2010, 2011b, 2012b, 2013a) and varied from .87 (fall) to .88 (spring) for the 2008-09 academic year; .87 (summer), .91 (fall), and .88 (spring) for 2009-10; .82 (summer), .88 (fall), and .84 (spring) for 2010-11; and .81 (summer), .87 (fall), .84 (spring) for 2011-12, .79 (summer), .92 (fall), and .88 (spring) for 2012-13. Reliability measurements for assessments given in the spring had far more students participating than in the summer or fall. Table 1 shows the number of students who completed the Biology EOC during each testing period from 2008-12.

DESE technical reports (2009; 2010, 2011b, 2012b, 2013a) note potential errors in measurement were reduced in the assessments through electronic scoring of student responses on the selected response sections; although, it is possible scoring errors may have resulted from improper coding or stray marks on scanned student bubble sheets. Finally, for the assessment years 2009, 2012, and 2013 the PE was hand scored by trained raters using rubrics that covered a wide range of student responses.

Table 1
*Total Number of Biology Students Who Completed the Biology EOC During the School Year**

School Year	Summer	Fall	Spring	Total
2008-09	Not Tested	1,855	55,732	57,587
2009-10	491	2,122	59,904	62,517
2010-11	384	2,391	62,068	64,843
2011-12	279	3,029	61,746	65,054
2012-13	321	2,837	62,355	65,513
M (SD)	369 (±92)	2,447 (±487)	60,361 (±2,759)	63,103 (±3,294)

*Data obtained from Missouri End of Course Assessments Technical Reports (DESE, 2009; 2010, 2011b, 2012b, 2013a)

Validity. DESE also provides evidence supporting the validity of the Biology EOC assessments in each year's technical reports (DESE, 2009; 2010; 2011b; 2012b; 2013a). DESE provides a variety of evidence including test content and internal structure of the assessment that supports the validity of the assessments for 1) measuring student mastery of standards, 2) identifying student strengths and weaknesses, and 3) program evaluation. DESE utilizes the patterns of relationships among the content domains and clusters using multitrait, multimethod matrices and then analyzes these domains clusters using Pearson correlation coefficients for discriminant validity evidence (DESE, 2012b). Additional information regarding measurements of validity or reliability for the state assessments can be found in these tech reports.

Sample

The number of school districts completing the biology assessment varied each assessment year with 457 completing the assessment in 2008-09, 464 (2009-10), 463 (2010-11), 462 (2011-12), and 464 (2012-13). This population was reduced into a sample of 235 Missouri schools for this study for consistency throughout the duration of the EOC. The process for selecting these 235 schools was based upon the following criteria. First, schools eligible for the study were required to have data from each year the assessment was administered (5 assessment years; 2009-2013). Second, additional data provided by DESE helped to determine at what grade level the biology assessment was typically administered (grades 9, 10, or 11). Third, schools were separated into specific course sequences and arranged into one of five different student groups (Grade 9 NPF, Grade 10 PF, Grade 10 NPF, Grade 11 PF, and Grade 11 NPF) after verifying the course sequences through direct contact (teacher, counselor, or administrator). These groups were identified according to grade level (9, 10, 11) and whether or not assessment results were from schools with a PF sequence or not (NPF). Table 2 shows the distribution of sample size within each test group.

Table 2
Distribution of Schools within the Sample's Test Groups

Grade	9		10		11	
Group	NPF	PF	NPF	PF	NPF	PF
Schools (#)	31	0	146	22	14	22

Figure 1 shows the distribution of the schools for each test group. The images were obtained from an online mapping program, and each placemark indicates a school within the sample. The distribution of schools within the sample indicates a large portion of the state has representation in the study.

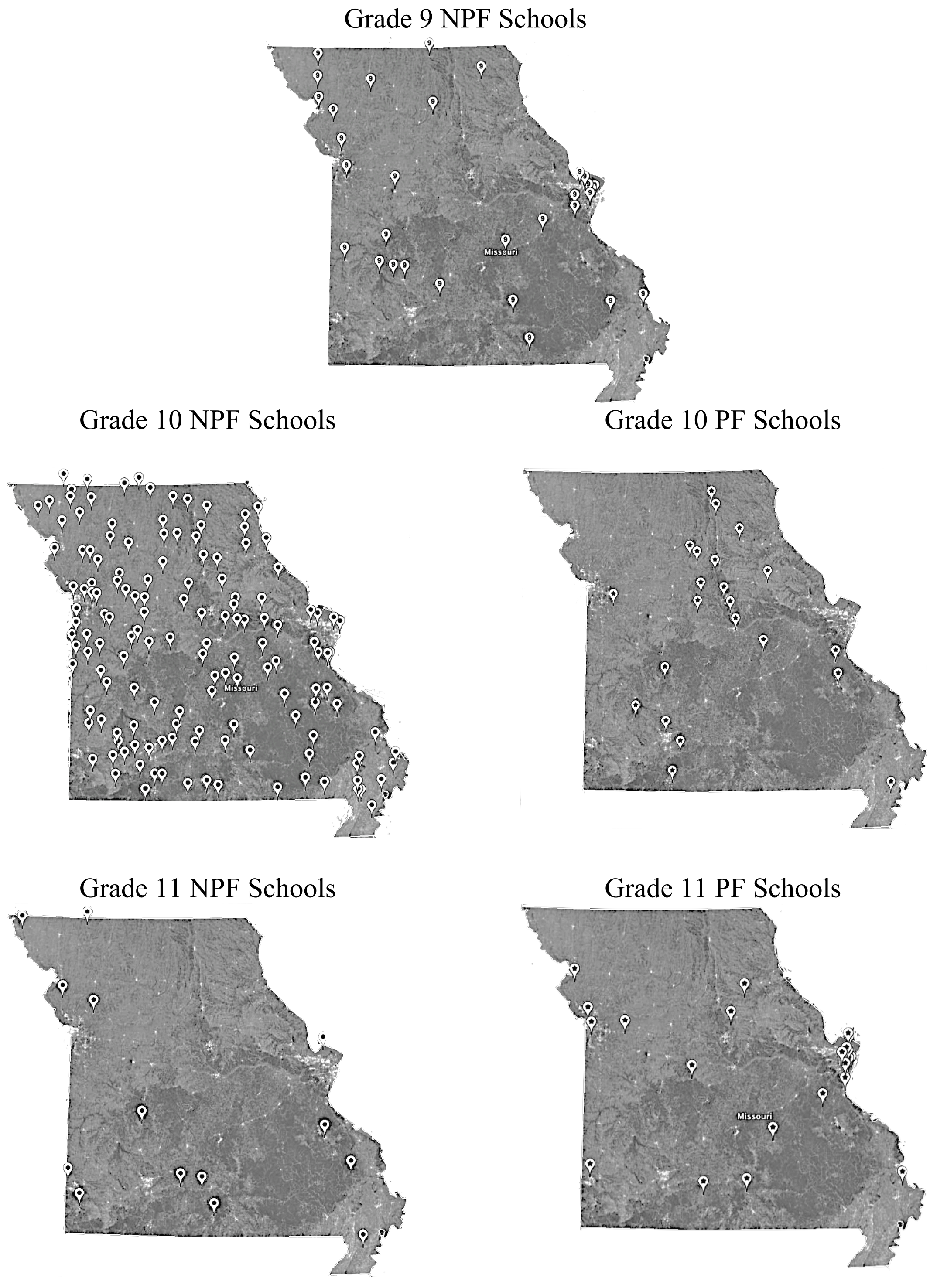

Figure 1. Google Earth® images of the Missouri school locations included in the sample.

Finally, data regarding the socio-economic status was utilized as part of the analysis. As each assessment year's data represented separate students, so did measurements of SES. Therefore, school SES values for each assessment year can be linked to those students completing the EOC assessment in the same year. Yearly SES values were provided by DESE and indicated the percentage of students completing the assessment who qualified for the FRL.

Statistical Analysis

Statistical analysis was done using a hierarchical linear modeling approach. Dorman (2008) notes that ignoring the dependency in data can give rise to misleading results; therefore, more sophisticated techniques that take account of the hierarchical structure of the data need to be utilized. While ordinary least squares regression is often used to analyze data toward explanatory and predictive ends, this approach carries the inherent assumption of *independence of observations*. In this study, a school's EOC assessment scores were dependent upon their previous EOC assessment scores. For example, a school with high EOC scores in 2009 is more likely to have high EOC assessment scores in 2010 than a school with lower EOC exam scores in 2009. Since the assumption of independent observations is violated, a 2-level hierarchical linear model was needed to account for this between-school dependency (Raudenbush & Bryk, 2002). Simulation work by Maas and Hox (2005) suggests that a sample size of 50 or more schools is likely to result in accurate model estimates (Maas & Hox, 2005). The sample size of 235 in this study far exceeds this recommended value. This approach allowed for the main effects variables to be analyzed through a two-level random intercept model that allowed for unique residual variance at each time point (heteroskedasticity).

If the assessment performance on the Biology EOC can be predicted (y) for each assessment year (YR) the exam is given (x) then the first level linear model ($y = b + ax$) is:

Within Schools

$$PA = b_0 + a_1 (YR)$$

GL and course sequence (SEQ) are "between schools" predictors for the 1st level prediction slope and intercept equation. The 2nd level prediction equations become:

Between-schools

$$b_0 = a_{00} + b_{01}(GL) + b_{02}(SEQ) + b_{03}(SES) + b_{04}(GL)(SES) + b_{05}(SEQ)(SES)$$

$$a_1 = a_{10} + b_{11}(GL) + b_{12}(SEQ)$$

Therefore, if the equation for the prediction of performance on the Biology EOC is:

$$PA = a_{00} + b_{01}(GL) + b_{02}(SEQ) + b_{03}(SES) + b_{04}(GL)(SES) + b_{05}(SEQ)(SES) +$$

$$[a_{10} + b_{11}(GL) + b_{12}(SEQ)] (YR)$$

Distributing terms:

$$a_{00} + b_{01}(GL) + b_{02}(SEQ) + b_{03}(SES) + a_{10}(YR)$$

$$+ b_{04}(GL)(SES) + b_{05}(SEQ)(SES) + b_{11}(GL)(YR) + b_{12}(SEQ)(YR)$$

Rewriting this equation in terms of the three portions: intercept, main effects, and two-way interactions.

PA =	
a_{00}	"Intercept"
$b_{01}(GL) + b_{02}(SEQ) + b_{03}(SES) + a_{10}(YR)$	"Main Effects"
$b_{04}(GL)(SES) + b_{05}(SEQ)(SES) + b_{11}(GL)(YR) + b_{12}(SEQ)(YR)$	"2-Way Interactions"

This final equation includes the following fixed effects: single intercept that represents the grand mean of the data, four main effects, and four two-way interaction terms. This model also includes the intercept as a random effect, meaning that each school is allowed a unique intercept (a_{00}) allowing it to vary randomly between schools. Rewriting this equation in terms of the four portions and subsequent Null Hypotheses to test for fixed effects is summarized in Table 3.

Table 3

Two-level nested design and null hypotheses for fixed effects

Term	Null Hypotheses
Main Effects	
b_{01}(GL)	H_{01}: There is no significant relationship between grade level (GL) and PA on the Missouri Biology EOC.
a_{10}(YR)	H_{02}: There is no significant difference in PA between assessment years (YR) on the Missouri Biology EOC assessment performance.
b_{03}(SES)	H_{03}: There is no significant relationship between socioeconomic status (SES) and PA on the Missouri Biology EOC.
b_{02}(SEQ)	H_{04}: There is no significant difference in PA between course sequences (SEQ) on the Missouri Biology EOC.
2-Way Interactions	
b_{11} (GL)(YR)	H_{05}: The relationship between assessment year (YR) and PA on the Missouri Biology EOC does not vary with the grade level (GL).
b_{12} (SEQ)(YR)	H_{06}: The relationship between assessment year (YR) and PA on the Missouri Biology EOC does not vary with course sequence (SEQ).
b_{04} (GL)(SES)	H_{07}: The relationship between socioeconomic status (SES) and PA on the Missouri Biology EOC does not vary with grade level (GL).
b_{05} (SEQ)(SES)	H_{08}: The relationship between (SES) and PA on the Missouri Biology EOC does not vary with grade level (GL).

Each was evaluated using the z-test in STATA 11 with any significant results determined through Chi Square analyses of log likelihood ratios. This was tested against linear regression with a random slope model that allowed assessment year (YR) to vary randomly to select the model with the least error. Finally, the model was further simplified using a leave-one-out variable subtraction as a measure of contribution of each variable to the model.

Statistical Assumptions

The analysis assumes that the data 1) follows a normal distribution (multivariate linear approach), 2) has a normally distributed error near zero (with a certain variance), and 3) does not have independent observations (groups are predetermined) which causes the groups to be nested.

Statistical Limitations

The data provided by DESE has shown that during the life of the assessment some schools have shown inconsistencies necessary for inclusion into this study. Schools with these inconsistencies were excluded and may have influenced data analysis and subsequent conclusions. The following list summarizes characteristics of schools excluded from this investigation:

- Schools have students testing at multiple grade levels.
    - Schools may have multiple science course sequences
    - Larger schools may allow individual high schools flexibility in sequences.
- Schools lack assessment data for all assessment years.
    - Lack of enrollment, opening or closing of schools, and consolidation may be contributing factors.
- Schools show testing has moved from one grade level to another during the assessment years.

    - As schools often change curricula, course sequences may have caused their Biology course to be repositioned.
- School sequences could not be validated.

Although the method resulted in an unbalanced design due to different sizes between the number of schools (Table 2) and reportable scores within these groups, work by Raudenbush (1993), Nezlek and Zyzniewski (1998), and Bell, Morgan, Kromrey, and Ferron (2010) suggest HLM gives flexibility to unbalanced designs by weighting a variable's contribution to the population mean with respect to group response reliability. Homer, Ryder, and Donnelly (2011) note student performance tends to be correlated with that of fellow students in their school. Therefore, HLM allows schools with smaller numbers of reportable scores to be compared to schools with larger populations with greater confidence. Dong (personal communication, November 11, 2014) stated ". . . in general, unbalance [designs] should not be an issue in the analysis of data using HLM as long as the same size per cluster is not very small (e.g., less than 5)." Traditional analysis of variance procedures ignore the organizational structure of the groups, thus a core assumption of ordinary least squares regression, independent observations, is violated in this study. The hierarchical statistical approach used overcomes the violations of independent observations (between schools, grade levels) by nesting between-schools variance into within-schools variance.

Summary

This chapter has described in detail how hierarchical linear modeling was used to determine the factors responsible for assessment performance in the Missouri Biology EOC while reducing the likelihood of errors from extraneous variables. The major assumptions and limitations to this approach have been identified including the description of reliability and validity of the EOC assessment instrument. Every school in this study had reportable scores for all assessment years (2009-13), and maintained the same science course sequence and grade level for the majority of students who completed the assessment. The sample size represents a wide selection of available schools across the state of Missouri for data analysis and can provide confidence for reasonable conclusions that can be applied at the school-level.

Chapter 4

Results

This chapter is divided into two main sections. The first section covers the descriptive statistics for the schools within the sample. It reviews the selection criteria for the sample, each group's sample size, and measures of socioeconomic status and assessment performance organized by grade and science course sequence (Tables 4 and 5). The second section summarizes the inferential statistics that result through hierarchical linear modeling (HLM). It compares the original 2-level model to other models with variables excluded and/or simplified models with the variables that were found to be statistically significant (Table 6 and 7). The chapter summary makes decisions about the investigation's null hypotheses and formally rejects those found to be significant.

Descriptive Statistics

There were 489 high schools considered for eligibility in this study. From this population 394 schools were eligible (reportable data for all assessment years [YR], maintained the same science curricular sequence [SEQ], and grade level [GL] assessed for 2009-13) and 95 were excluded (lack of data from all assessment years, inconsistencies in grade level testing, or changes in sequence). Based upon verification of course sequencing and history by phone conversation or email exchange with school personnel, this sample was reduced to 235 valid data sources for statistical analysis with schools that had consistent characteristics relating to GL and SEQ independent variables. Although this represents less than one half of Missouri's secondary schools it includes an average of 39,615 students per assessment year for the analysis. This means these results account for nearly 63% of all Missouri students who completed the Biology EOC from 2009-13.

Table 4 shows the descriptive statistics for reportable scores in Missouri schools for each assessment year (2009-13). Each test group (Grade 9 NPF, Grade 10 NPF, Grade 10 PF, Grade 11 NPF, and Grade 11 PF) represents the grade level and science course sequence in which the majority of the each school's students completed the Biology EOC. Reportable values represent the cumulative total number of students from all schools in the sample for that group. Minimum and maximum values show that some schools had very few students completing the assessment and other were much larger. Average reportable scores for each test group in this sample was 311 $\pm$ 439 for Grade 9 NPF schools (n=31), 115 $\pm$ 248 for Grade 10 NPF schools (n=146), 223 $\pm$446 for Grade 10 PF schools (n=22), 86 $\pm$95 for Grade 11 NPF schools (n=14), and 323 $\pm$381 for Grade 11 PF schools (n=22). Ninth grade students (Grade 9 NPF) would have completed their biology course and subsequent assessment without having any opportunities for a PF curricular sequence in high school. An overwhelming majority of students in the state of Missouri for this study completed the assessment during grade 10, but only a few of those schools (n=22) used a PF curriculum during grade 9. The Grade 10 PF group was not initially anticipated since the PF approach recommends completing chemistry in grade 10 prior to completing the sequence in grade 11 with biology. It is not known whether these schools had been using the PF sequence prior to changes in science requirements for graduation (two units was switched to the current three credits with the graduating class of 2010) and selected to maintain their existing course sequence.

Table 4

Descriptive statistics for the number of total reportable scores in school groups for 2009-13

		Year						
Group	Measure	2009	2010	2011	2012	2013	*M*	*SD*
Grade 9 NPF	Reportable	10,086	9,718	9,580	9,389	9,458	9,646	275.92
(n=31)	Range	2,006	1,996	1,889	1,876	1,927	1,939	59.90
	Min	6	5	8	3	5	5	1.82
	Max	2,012	2,001	1,897	1,879	1,932	1,944	60.11
	M(SD)	325(465)	313(445)	309(435)	303(432)	305(444)		
Grade 10 NPF	Reportable	16,229	16,886	17,188	16,367	17,124	16,759	438.17
(n=146)	Range	1,756	1,918	1,838	1,513	1,609	1,727	165.35
	Min	2	4	2	5	5	4	1.52
	Max	1,758	1,922	1,840	1,518	1,614	1,730	164.43
	M(SD)	111(243)	116(254)	118(264)	112(233)	117(249)		
Grade 10 PF	Reportable	4,884	4,833	5,032	4,832	4,941	4,904	84.23
(n=22)	Range	1,699	1,721	1,892	1,659	1,844	1,763	99.85
	Min	8	10	9	1	8	7	3.56
	Max	1,707	1,731	1,901	1,660	1,852	1,770	101.83
	M(SD)	222(435)	220(445)	229(462)	220(425)	225(455)		
Grade 11 NPF	Reportable	1,105	1,185	1,214	1,124	1,375	1,201	107.06
(n=14)	Range	231	295	291	237	513	313	115.44
	Min	17	21	21	7	17	17	5.73
	Max	248	316	312	244	530	330	116.88
	M(SD)	79(75)	85(92)	87(88)	80(77)	98(140)		
Grade 11 PF	Reportable	6,338	6,931	7,569	7,538	7,149	7,105	505.79
(n=22)	Range	1,180	1,192	1,309	1,332	1,260	1,255	67.94
	Min	1	32	42	7	29	22	17.43
	Max	1,181	1,224	1,351	1,339	1,289	1,277	73.30
	M(SD)	288(354)	315(369)	344(410)	343(414)	324(386)		

Students in the Grade 11 groups (11 NPF and 11 PF) were of greatest interest. First, these students were assumed to be the oldest students compared to grade 9 or 10. Second, schools in the Grade 11 PF group (n=22) had completed a complete PF sequence (PCB), and could represent the influence of utilizing the sequence for science curriculum recommendations.

Assessment performance results (*M, SD*) as indicated by the percentage of students scoring Proficient or Advanced (PA) for each group and associated socioeconomic status (*M, SD*) as measured by FRL in the study for each assessment year is summarized in Table 5. Schools that completed the assessment in Grade 9 would only have students enrolled in Biology; therefore no data is available for Grade 9 PF. There were fewer numbers of Grade 10 and 11 PF schools (n=44) that completed the assessment than Grade 9, 10 and 11 schools using a NPF sequence (n=191).

The data shows an overall increase in PA for all groups from 2009-13. Grade 9 NPF schools increased PA from 54.22 $\pm$15.53 in 2009 to 69.85 $\pm$18.52 in 2013 for a 15% gain. These gains are consistent with all other groups as well with 2009 through 2013 in Grade 10 NPF (+21%), Grade 10 PF (+21%), Grade 11 NPF (+25%), and Grade 11 PF (+23%). Although the overall gains are consistent, the data also shows an interesting event with the PA in all groups dropping in 2012 compared to results from 2011, but then rebounding in 2013 with higher values than any of the preceding assessment years.

Results by grade level did not show any significant linear trends; however, some unusual patterns did emerge. Grade 10 NPF schools had lower PA scores than Grade 9 or Grade 11 for most assessment years. For example, in 2009 Grade 9 schools scored 54.21 $\pm$15.53 compared to 52.23 $\pm$17.15 for Grade 10, and then 54.57 $\pm$13.81 for Grade 11.

This pattern continues for all assessment years with the exception of 2013. The data also reveal that Grade 11 students had higher PA than either Grade 9 or 10 for each assessment year. This pattern was observed for PF schools where Grade 11 schools had higher PA values than Grade 10 for each assessment year. It was also interesting to note that for some assessment years Grade 9 NPF schools had higher PA (2010: 58.31 $\pm$15.15; 2012: 55.25 $\pm$12.20) than Grade 11 PF schools (2010: 57.20 $\pm$16.23; 2012: 53.13 $\pm$16.02).

Data from SES measures showed little differences between test groups with most measures of FRL around 50% for each test group for each assessment year. FRL percentages appeared to be lowest for Grade 9 NPF from 2009 (42.55 $\pm$18.54) through 2013 (47.67 $\pm$18.95). The other test groups had higher values for FRL than Grade 9 but were rather consistent between the groups. It was interesting to note the trend in FRL values from 2009-13. With little exception nearly all groups showed an increase in FRL from 2009-13. FRL values showed Grade 9 NPF increased 5% (42.55 to 47.67), Grade 10 NPF increased 6% (49.65 to 55.99), Grade 10 PF increased 7% (47.43 to 54.52), Grade 11 NPF increased 4% (51.83 to 55.89) and Grade 11 PF increased 5% (46.61 to 51.89).

Inferential Statistics

The main goal of the HLM was to determine which model adequately represented the trend of the data while retaining parsimony. Keeping the model as simple as possible tends to reduce the effect of confounding results caused by unimportant variables (Pham Nguyen & Triantaphyllou, 2008). Likelihood ratio tests (chi square) were performed to compare the efficacy of using a hierarchical random intercept model versus ordinary linear regression. The random intercept model fit the data significantly better than a single-intercept model ($\chi^2_{df=5} = 232.38$; $p<0.0001$), thus warranting selection of the random intercept model as the framework for interpreting the data.

Table 5

Grade level (9, 10, 11) end of course performance (PA) and socioeconomic status (FRL) for non physics first (NPF) and physics first (PF) schools by assessment year

		Grade 9 (n=31)				Grade 10 (n=168)				Grade 11 (n=36)			
		PA (%)		FRL (%)		PA (%)		FRL (%)		PA (%)		FRL (%)	
Sequence	Year	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
NPF	2009	54.21	15.53	42.55	18.54	52.23	17.15	49.65	13.92	54.57	13.81	51.83	17.82
(n=191)	2010	58.31	15.15	45.23	19.03	53.48	17.03	53.05	13.98	59.29	12.71	54.80	17.05
	2011	60.43	14.01	46.03	18.71	57.77	15.37	53.67	14.02	63.51	13.39	55.31	15.96
	2012	55.25	12.20	46.90	18.45	52.13	14.37	55.13	14.40	57.25	11.31	55.96	16.27
	2013	69.85	18.52	47.67	18.95	73.43	11.81	55.99	13.97	80.03	12.19	55.89	17.09
PF	2009	NA	NA	NA	NA	54.80	17.94	47.43	13.65	55.25	20.11	46.61	18.79
(n=44)	2010	NA	NA	NA	NA	56.76	11.49	51.49	13.92	57.20	16.23	49.04	19.07
	2011	NA	NA	NA	NA	58.43	12.41	52.38	13.19	60.47	17.03	49.48	19.11
	2012	NA	NA	NA	NA	50.64	15.21	54.10	13.94	53.13	16.02	51.33	20.07
	2013	NA	NA	NA	NA	75.96	10.75	54.52	14.03	78.46	9.60	51.89	20.27

NA: Not applicable

Table 6 shows the results of the variable subtraction and model reduction process. Statistical comparisons were performed to determine the variables that impacted the model by determining whether or not eliminating a variable significantly reduced model fit. The full model included all fixed effects and interactions (YR, SES, SEQ, GL, YR x GL, YR x SEQ, GL x SES, SEQ x SES).

Analysis of the variable subtraction process indicated that YR ($\chi^2_{df=4} = 54.46$; $p<0.0001$) and SES ($\chi^2_{df=1} = 12.81$; $p=0.0003$) fixed effects were the only variables that would significantly reduce the fit of the model if they were excluded. Removing GL ($\chi^2_{df=2} = 0.64$; $p=0.73$) or SEQ ($\chi^2_{df=1} = 0.17$; $p=0.68$) as well as the interactions (YR x GL, YR x SEQ, GL x SES, and SEQ x SES) did not significantly change the model providing statistical evidence to support the notion these factors have no significant effect on assessment performance.

A simplified linear model was constructed to include only YR and SES variables. The fit of this reduced model to the data was not statistically different than the original ($\chi^2_{df=18} = 24.02$; $p=0.15$). This justifies the sole use of YR and SES for explaining the data. Comparisons were made between the simpler model to one that included the significant variables (YR, SES) and their interaction (YR x SES). This interaction analysis was important to determine whether SES as measured by the percentage of free and reduced lunches in a school influences assessment performance from 2009-13. This model comparison showed no significant improvement in fit when the interaction was added to the model ($\chi^2_{df=4} = 2.69$; $p=0.61$). This indicates that the trend over assessment years is not influenced by changes in SES; although, schools with higher percentage of students in %FRL initially start lower and remain below schools with lesser %FRL, they continue to make the same gains from assessment year to year.

Table 6
Hierarchical linear modeling analysis for fitness between full model and modified models (single variables excluded, or simplified models with fewer variables included).

Treatment	Variable	χ^2	df	p
Single Variable Excluded Models[a]				
Main Effects	Year (YR: 2009-13)	54.46	4	<0.0001*
	Socioeconomic Status (SES: FRL)	12.81	1	0.0003*
	Sequence (SEQ: NPF, PF)	0.17	1	0.6804
	Grade (GL: 9, 10, 11)	0.64	2	0.7255
Interactions	YR x GL	12.58	8	0.1289
	YR x SEQ	2.81	4	0.5909
	GL x SES	0.38	2	0.8266
	SEQ x SES	0.14	1	0.7092
Simplified Models with Included Variables				
	YR, SES	24.02[b]	18	0.1545
	YR, SES, YR x SES	2.69[c]	4	0.6104

[a] Elimination of variable from the full model
[b] Comparison to the full model
[c] Comparison to the reduced model (YR, SES)
*Significant (p<.05)

Table 7 summarizes the results of this simplified model analysis where YR and SES variables were tested to determine whether their values were significantly different than zero. The two variables included in this model establish the baseline prediction coefficient constant that schools in 2009 that had 0% FRL would likely produce 69.59% of their students scoring proficient or advanced. Each assessment year 2010-13 was compared to 2009, and SES was compared to 0% FRL. Each assessment year with the exception of 2012 showed significant increase relative to the assessment performance measures from 2009. The coefficient values for YR (Table 7) represents the change in the intercept (PA) from the Constant (69.59), and shows a gradual, significant increase from 2010 (3.07; p=0.009) through 2013 (22.94; p<0.0001), but only a slight variation in 2012, which was not significantly different from 2009 (p=0.195).

SES values showed a negative trend (-0.34) compared to the constant indicating that as the %FRL increased assessment performance decreased.

Table 7
Simplified model utilizing assessment year (YR) and socioeconomic status (SES) as predictors of assessment performance

Variable		Coefficient	Standard Error	z	P>|z|	95% Confidence Interval	
						LL	UL
YR	2010	3.07	1.18	2.60	0.009*	0.76	5.38
	2011	6.94	1.17	5.93	<0.0001*	4.65	9.24
	2012	1.44	1.11	1.30	0.195	-0.74	3.62
	2013	22.94	1.10	20.75	<0.0001*	20.78	25.11
SES		-0.34	0.04	-8.94	<0.0001*	-0.41	-0.26
Constant		69.59	2.11	32.99	<0.0001*	65.45	73.72

*Significant (p<.05)

These results allow for each research question and hypothesis to be addressed. The first question tested if there is a significant relationship between high school Grades 9-11 in Missouri and the Biology EOC assessment performance. Grade level had no significant effect on PA (p=0.73). The second question asked if there is a significant difference in high school course sequence in the Missouri Biology EOC assessment performance. The results for the SEQ fixed effects variable showed no significant influence on PA ($p=0.68$). Question 3 asked if there is a significant difference between assessment years 2009-2013 in the Missouri Biology EOC assessment performance. The assessment year significantly influenced PA ($p<0.0001$) and is graphically represented in Figure B1 (Appendix B). Question 4 asked if there is a significant relationship between the SES as measured by FRL in a school and the Missouri Biology EOC assessment performance. Like YR, this fixed effect was also found to be a significant variable that would affect PA ($p=0.0003$) is graphically represented in Figure B2 (Appendix B). The fifth question was added after the influence of YR and SES was specified. It asked if SES as measured by the percentage of free and reduced lunches in a school influences assessment performance trends by YR (from 2009-13). The analysis indicates it does not ($p=0.61$), meaning that any gains in PA result from the independent role of each YR and SES variable.

Table 8 summarizes the findings of this study in reference to the hypotheses. All statistical analyses were completed using the HLM approach and used Chi Square values to determine significance between models when main effects and/or interactions were or were not included.

Summary

The first section of this chapter summarized the descriptive statistics of the study. These results included a description of each group's sample size as well as measures for assessment performance and socioeconomic status. These reportable scores represent approximately 63% of all students who completed the Biology EOC assessment from 2009-13 providing an adequate sample for the study.

Table 8

Summary of findings within two-level nested design and null hypotheses for fixed effects and interactions

Term	Null Hypotheses	Result
Main Effects		
GL	H_{01}: There is no significant relationship between grade level (GL) and PA on the Missouri Biology EOC.	Not Rejected
YR	H_{02}: There is no significant difference in PA between assessment years (YR) on the Missouri Biology EOC assessment performance.	Reject
SES	H_{03}: There is no significant relationship between socioeconomic status (SES) and PA on the Missouri Biology EOC.	Reject
SEQ	H_{04}: There is no significant difference in PA between course sequences (SEQ) on the Missouri Biology EOC.	Not Rejected
2-Way Interactions		
(YR)(GL)	H_{05}: The relationship between assessment year (YR) and PA on the Missouri Biology EOC does not vary with the grade level (GL).	Not Rejected
(YR)(SEQ)	H_{06}: The relationship between assessment year (YR) and PA on the Missouri Biology EOC does not vary with course sequence (SEQ).	Not Rejected
(SES)(GL)	H_{07}: The relationship between socioeconomic status (SES) and PA on the Missouri Biology EOC does not vary with grade level (GL).	Not Rejected
(SES)(SEQ)	H_{08}: The relationship between (SES) and PA on the Missouri Biology EOC does not vary with grade level (GL).	Not Rejected
(YR)(SES)	H_{09}: The relationship between socioeconomic status (SES) and Biology EOC assessment performance does not vary by assessment year (YR)	Not Rejected[a]

[a]Results compared to reduced, simplified model

The number of students completing PF science course sequences in Missouri is much smaller than schools that do not. Finally, a majority of the schools have students completing biology in Grade 10 indicating biology is in the middle of their sequence.

The second section incorporated those values into HLM analysis to determine which fixed effects and interaction variables might contribute significantly towards the model's fitness. The results showed two of the fixed effects variables, YR ($p<0.0001$)

and SES (p=0.0003), significantly described the data. It also shows when the model is simplified to only include these two variables it is not statistically different (p=0.15) than the larger model with all fixed effects and interactions included.

Chapter 5

Summary of Study, Conclusions, Discussion, and Recommendations for Future Studies

This chapter begins by summarizing the important findings from this study that may contribute to the knowledgebase for Missouri school leaders making important decisions regarding which science curriculum sequence is appropriate for their school. The scope of this study rests on how these factors influence performance on the Missouri Biology EOC assessment. The major conclusions of the study regarding science course sequence, grade level, assessment year, and socioeconomic status are summarized. The discussion section includes a review of states that currently use EOC assessments and how this study may provide implications beyond the state of Missouri. This section also includes analysis of the main effects variables (YR, SES, SEQ, and GL) and how other related research studies may or may not support this study's conclusions. Finally, recommendations for future studies in the areas of school characteristics, scientific reasoning, and the Next Generation Science Standards implementation are suggested. Other issues that should be considered by school leaders who are in the process of selecting a PF or alternative science curriculum sequence are discussed.

Summary of Study

The purpose of this study was to determine if a PF science sequence in Missouri high schools would produce superior outcomes in Biology EOC assessment performance compared to other sequences. The traditional BCP science course sequence in high schools has remained relatively unchanged (Wilt, 2005) for over 100 years. In 1892 the

CoT recommended that high school students receive a full course in chemistry prior to taking physics although a minority had an alternative view. They suggested physics was a foundational science and would be needed for understanding other areas of science students were likely to study later in their high school years (Sheppard & Robbins, 2003). Lederman (2001) revisited this approach advocating a change to a first course in physics approach. The AAPT (2002) soon published a position statement that supported the implementation of a coherent, grade 9-11 PCB sequence for high school science that varied from the traditional sequence (BCP). AAPT argued a first course in physics was needed as foundational prerequisites to understand the abstract nature of chemistry and biology principles while at the same time aligning with typical ninth grade goals in basic algebra. Although some schools in Missouri have implemented PF programs the majority have yet to change their science sequence. Of the 235 schools observed in this study, all have maintained their current high school science course sequence from the 2008-2009 to the 2012-2013 academic years, and 191 were using an alternative high school science NPF sequence in preparation for students completing coursework in biology. Many schools in this study begin their high school sequence with a biology course in grade 9. This population provided a unique opportunity to investigate the influence of science course sequence for those schools that have utilized a PF approach.

There are limited studies with large-scale or long-term studies of PF's influence. Those referenced by AAPT are generally smaller in scale. A summary of these studies include research in mathematics (Deakin, 2006; Glasser, 2004; Schuchardt, Malone, Diehl, Harless, Mcginnis, & Parr, 2008), physics (Burgess, 2009; Bouma, 2010; Obrien & Thompson, 2009), chemistry (Burgess, 2010), biology (Burgess & Goff, 2011), scientific reasoning (Williams, 2009), and increased enrollment and interest in science courses (Goodman, 2006; Mountz, 2006; Vallette, 2007; Walker, 2008). However, data from this study has provided a large sample of how the high school science course sequence may influence Biology EOC assessment performance. This study represents a large portion of the state of Missouri and covers five assessment years (2009-2013).

Like many other states (Dounary Zinth, 2012) Missouri utilizes a Biology EOC assessment as their measure of high school science proficiency to satisfy requirements for state and federal NCLB (2002) guidelines. According to their technical reports, DESE (2009, 2010, 2011b, 2012b, 2013a) considers the EOC a valid and reliable instrument for measuring proficiency in biology. Each student who completes the assessment is ranked into one of four proficiency categories (Below Basic, Basic, Proficient, and Advanced), and when combined for all reportable scores for a school, the school's proficiency status is determined by the combined percentage of students who score in the Proficient and Advanced categories. This PA data was used as the dependent variable in this study.

There were 489 high schools considered for eligibility in this study. While the number of school districts completing the biology assessment varied each assessment year (457 in 2009, 464 in 2010, 463 in 2011, 462 in 2012, and 464 in 2013) there were 394 schools with reportable scores from 2009 through 2013 assessment years. A final sample of 235 schools was included in this study. These schools maintained their science course sequence and the high school grade level (9-11) in which the majority of students were assessed in Biology. Test groups in this study were organized into schools that utilized a PF sequence compared to those that did not for each grade level. This resulted in five unique groups (Grade 9 NPF, Grade 10 NPF, Grade 10 PF, Grade 11 NPF, and

Grade 11 PF) for analysis. Hierarchical linear modeling allowed for the inclusion of these independent variables (assessment year, grade level, science course sequence) and each school's socioeconomic status (FRL) into a 2-level, random intercept statistical model. This complete model was compared to simplified models in order to minimize error and determine the variables that provided significant influence on PA.

School data provided by DESE indicated the number of students in each grade level that tested per assessment year. This data revealed students across Missouri were completing the Biology EOC in many different high school grade levels. Direct communication with schools verified the science course sequence and grade level tested for students completing the state Biology EOC assessment was maintained for each assessment year in each school. The full PF sequence places Biology last in a sequence after physics in ninth grade and chemistry in grade 10. Although this is the ideal format for a PF sequence, some schools that tested in grade 10 indicated they used a first course in physics for grade 9.

Missouri PF schools that met the criteria for inclusion into the study were compared to schools with alternative sequences. However, the study indicates neither science course sequence, grade level, nor any of the interaction variables (YR x GL, YR x SEQ, GL x SES, SEQ x SES) influenced performance on the Missouri Biology EOC assessment. This study shows from 2009-13 there were only two factors that influenced PA; 1) the year the assessment was completed (2009-13), and 2) the socioeconomic status of the school as measured by FRL. Since the inception of the Biology EOC assessment in 2009 scores have continued to increase significantly through 2013, and as the FRL increases their PA significantly decreases.

Finally, the two remaining variables (GL and SEQ) did not significantly affect the Biology EOC assessment performance. There were no significant differences in PA for schools that test in grade 9 compared to grade 10 or 11. Also, there was no significant difference in PA on the Biology EOC assessment between schools that utilize a PF sequence compared to those that did not.

Conclusions

Science Course Sequence and Grade Level. Neither high school science sequence (SEQ) nor grade level (GL) affected PA. Therefore, it doesn't matter what science course sequence students complete, or grade level in high school in which students are enrolled in order to reach proficiency on the Missouri Biology EOC. The efficacy of physics as a first course in the high school science sequence and as content being essential for students to learn biology (AAPT, 2002) was not supported by this study of Missouri students. This study compared statistical models with and without SEQ and GL main effects. When SEQ is excluded the model's fit was not changed significantly indicating the lack of influence course sequence had on PA. Similar results were observed with GL.

Assessment Year. The PA in Missouri biology students increased significantly from the 2009 through 2013 assessment years. Improvements in Biology EOC performance from 2009 to 2013 were evident, although there appeared to be a slight decline in 2012. A review of the technical reports provided by DESE (2009, 2010, 2011b, 2012b, 2013a) suggests each assessment allowed for consistent measures of PA based upon the Biology EOC. It may be argued that subsequent assessment years beyond 2009 somehow resulted in progressively easier assessments so that student performance would increase, but no evidence to support this argument was found within these reports. However, there have been changes to the assessment throughout its duration. Assessment years 2009, 2010 and 2013 included a PE while the 2011 and 2012 assessment years did not. It was assumed that any measures relating to consistency from year to year for the assessment had been vetted by DESE through its processes of assessment development, assessment item content and bias review, and level-setting for determining proficiency.

Socioeconomic Status. The other significant factor that influenced PA showed a negative trend when FRL was included. As the FRL increased PA decreased. However, even though schools with high rates of FRL tended to perform lower than more affluent schools it was interesting to discover in the simplified statistical model assessment performance gains over time were similar.

Discussion

End of Course Assessments. A survey by Dounary Zinth (2012) reported 21 of 22 states in the United States currently administered Biology EOC assessments (the most assessed subject area) to all students. Eight of these states required students used EOC assessments for high school graduation requirements with the number increasing to 15 states by 2020. Eleven states, including Missouri, currently administer EOCs, but have no graduation or passing requirements. Since Missouri is one of the 21 states that assess Biology using an EOC the conclusions of this study may be applicable to other states. It is recognized each state utilizes its own EOC assessment.

Missouri's Biology EOC assesses various expectations indicated in the CLE document (Appendix A, DESE, 2008b) that are aligned to either content or process standards common to the discipline of biology. However, some of the expectations are included in the CLEs but are not assessed on the Biology EOC. DESE (2008b) recommends these expectations be included in curriculum, but should be assessed locally.

Assessment Year. Since students complete the assessment only one time; consequently each year's results indicate a new group of students' performance. This suggests that improvements relating to proficiency from assessment years 2009 to 2013 might be attributed to school-level factors not attributed to individual students. One of these factors may include the ability of the schools to improve effective instruction to achieve knowledge and performance standards on the Biology EOC assessment. Biology teachers in these schools may be improving their ability to prepare their students for success on these large-scale assessment systems as a form of accountability (Britton & Schneider, 2008).

Modifications in science instruction in each school were not controlled in this study yet were assumed to occur. Since professional development (PD) programs are a regular part of school improvement in Missouri (DESE, 2013b), ongoing PD programs that target improvement relating to standards that have existed for several years may produce improved assessment results by modifying teaching practices. Many PD programs attempt to improve the pedagogical content knowledge (PCK) of the participants through a variety of strategies. Programs designed to improve content knowledge, encourage teacher leaders, implement a particular strategy, learn more about student learners, or gain insight into curriculum and/or assessment may all play a role in increasing student performance. Typical PD incorporates a blending of strategies (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2010), but in recent years the predominant target has been immersion in inquiry-based teaching and or combined with content courses. This aligns with the PD Standard A in the *NSES* (NRC, 1996) that emphasizes the role perspectives and methods of inquiry and increased subject matter knowledge (SMK) play in the learning of essential science content. Successful PD programs can attempt to improve teacher SMK as well as PCK, provide resources, promote professional learning communities and collegiality, and promote teacher leaders through research-based activities that engage the participant as an adult learner.

Although it didn't seem to impact the results over time the slight dip in PA in the 2012 assessment year followed by the gains in 2013 may require further review. If educators had only been focusing on content knowledge it might be explained by results from work by Taylor, et. al, (2008) where they found teachers focused mainly on improving test scores with little emphasis on in-depth inquiry investigations for test preparation. Additionally, in the 2012-2013 academic year the PE that measured scientific inquiry goals was reintroduced. The PE was part of the previous assessment program first introduced in 1993 and later included with the introduction of the Biology EOC during the 2008-09 academic year (DESE, 2011b). DESE (2013c) performed an analysis to explain the gains present in the results from 2013. When assessment data from the PE was excluded measures of proficiency were consistent with the two previous assessment years results (2011 and 2012). Since the PE's score accounted for nearly one-third the total score on the assessment, DESE concluded the growth in the Biology EOC was attributed to improved student achievement on the PE. Finally, the 2012-2013 assessment year was the first time Biology EOC data was used in Missouri's school accreditation process. DESE (2013c) suggests this accountability influence may have contributed to the 2012-2013 assessment year increases in PA.

Socioeconomic Status. This study used measures of FRL as indicators of SES, and results showed schools with higher FRL (lower SES) had significantly reduced assessment performance. Lower SES is generally accepted to have negative effects on children's performance (Letourneau, Duffett-Leger, Levac, Watson, & Young-Morris, 2013). Sirin (2005) noted in a meta-analytic review that parental income (the main basis for enrollment in FRL) reflects the potential for social and economic resources that are available to the student; therefore, enrollment in FRL is a good indicator of SES status. Sirin's (2005) analysis of 167 independent correlations of SES and science achievement from 1990-2000 in the United States resulted in an effect size of .27 with a large degree of association at the school level. He suggests the family's SES "sets the stage" (p. 438) for performance in academics due to the availability of resources and income to support school (and even classroom) choice.

Science Course Sequence and Grade Level. Biology is a regular part of the high school science course sequence, and schools across Missouri vary when Biology is offered. Do the students in Missouri high schools need one, two, or even three courses in order to produce greater PA? This study indicates the PF curricular sequence (PB or PCB) does not produce a significantly higher PA on the Biology EOC assessment than schools utilizing alternative sequences. These results run contrary to recommendations by Lederman (2001), AAPT (2002), and BSCS (2006) who have suggested the PF sequence would provide a solid foundation for the learning of other science content as a first course in science, and that it is essential for the learning of chemistry and biology. This study has shown that schools that offer Biology in 9th grade have similar PA as schools that take three years to complete a sequence culminating in Biology in grade 11.

Clay, Fox, Grunbaum, and Jumars (2008) recognized the distinct separation of biology, physics, and mathematics in the high school curriculum, although they are often used to address biological concepts. They emphasize the interconnected nature of these disciplines may provide unique opportunities to explicitly connect mathematics and physics ideas in the biology classroom. However, their study revealed two interesting findings. First, biology students were unable to transfer and integrate mathematical skills into a biology activity that was structured to include explicit connections to physics concepts; therefore, they had to introduce a lesson on the use of the necessary mathematical skills in order for students to develop understanding. Second, pre/post test results indicated only 2 of 4 questions directly tied to biology concepts (marine biology, plankton) showed significant gains.

Sadler and Tai (2007) have also found that cross-disciplinary coursework in science classes does not necessarily improve measures of performance, and " . . . casts doubt on the impact of changing the traditional high-school science sequence" (p. 458). This study concluded high school course sequence has little to do with assessment performance in biology.

Although the two volumes of the *Atlas of Science Literacy* (AAAS, 2001; 2007) demonstrate interconnected concepts between physics, chemistry, and biology, it does not recommend a specific science course sequence where these concepts should be learned within the high school grade span. When large-scale assessments are mandated, research has shown teachers will focus solely on those goals directly assessed (Taylor, et. al., 2008, Lee, et. al., 2009). If the Missouri Biology EOC assesses learning goals where connections to physics are lacking then the need for PF may be irrelevant. However, if there are physics ideas essential for understanding at least some concepts in biology, it may be likely these concepts are not being assessed on the Biology EOC. Currently, there are two Biology CLEs (Appendix A) directly related to physical science concepts, and neither is assessed on the EOC.

This study found no significant differences between biology PA influenced by GL; therefore, Missouri biology students EOC performance in grade 9 is no different than higher grades. This study's results are similar to grade level comparison studies cited by AAPT (2013). Bouma (2010) compared physics assessment performance on the California State Test in Physics between students completing PF in grade 9 to grade 12 senior physics students receiving traditional physics instruction. His average results over three years showed comparable assessment performance results (61.4% for grade 9; 56.8% for grade 12). Burgess and Goff (2011) compared results on a 25 multiple choice question examination where his items were obtained from a released 2002 AP Biology Examination. The results showed the scores from grade 11 AP Biology students who participated in a PF sequence were slightly higher than grade 12 students from a different sequence, but the results were not significant.

Learning science concepts in high school may have little to do with the order of any particular science course sequence or particular grade level in which the content is learned. BSCS (Bybee & Bloom, 2008) summarized research from the National Research Council (Bransford, et. al, 2000; Donovan & Bransford, 2005) focusing on three key factors impacting student learning in science. First, their summary indicated for students to develop scientific understanding and understand complex scientific principles it is important to organize science knowledge into conceptual frameworks. Second, students must also be able to synthesize interconnected ideas through many meaningful learning experiences, and utilize multiple representations to demonstrate understanding of scientific ideas. Third, for deep learning to occur, students must connect scientific concepts to explain the phenomena present in real world situations.

The results from this study may also support conclusions by Lazarowitz (2008) in a summary of research relating learning biology to the cognitive abilities of students. Lazarowitz concluded when teachers are aware of the cognitive abilities of their students learning material, instructional methods, and the classroom environment can be restructured to accommodate and produce successful outcomes. When schools show higher levels of PA in this study could it be 1) biology teachers are focusing primarily on those concepts that will be assessed, and/or 2) are able to adequately help students organize appropriate conceptual frameworks where neither of these require connections to physics, grade level or even ultimately assessed on the Biology EOC?

Recommendations for Future Studies

The intent of this section is to provide direction to researchers for future studies that seek to investigate high school science course sequence as well as other factors that influence PA. If maximum student learning and performance on high stakes tests like the Biology EOC are what is desired then much research is needed in the characteristics of the 21st century learner as well as the science classrooms they enter. However, the common thread from year to year is typically the teacher, and it is the teacher who provides the conduit between curricular programs and student learning in the classroom.

School Characteristics. Many questions remain for schools when making science curriculum sequence decisions and a few have been previously presented. Although this study represented a large sample across the state of Missouri it was limited in describing school-level outcomes. Schools ranged from a single classroom in one building per assessment year, to hundreds of students in multiple classrooms, different teachers, and/or different buildings. Questions remain around individual student, teacher, classroom, and building characteristics leaving room for closing the gap determining what actually occurred in the classroom to produce the results.

School student data provided by DESE may reveal patterns associated with disaggregated populations (race, gender, special education, etc.) and/or individual achievement bands (Advanced, Proficient, Basic, Below Basic) but as these students change from year to year improvements in science assessment performance through longitudinal studies are warranted. Missouri currently administers a comprehensive science assessment to all 8th grade students. This assessment measures overall proficiency in science and includes assessment items in many science disciplines (Physical Science, Life Science, Earth and Space Science, Scientific Inquiry and Relevance). Studies might investigate individual improvement from middle school to high school within or between achievement bands given the variables in this study through longitudinal analysis.

Characteristics of individual teachers and their classrooms may be closer to answering the questions behind successful programs that are able to consistently achieve higher levels of PA on assessment like the Biology EOC. What were the science teacher PD programs from 2009-13 for the schools in this study? What science content and/or science process standards were emphasized during this time? What opportunities for in-depth inquiry investigations were available to students? Will science course sequencing influence performance on other or future assessments used to measure learning or skills related to science? Should other states replicate this study to find whether similar patterns and conclusions exist or not? This section expands on some of these questions as recommendations for future research relating to science course sequencing in high schools.

Another area of study is to investigate the influence of other coordinated curricular sequences similar to PF. Sheppard and Robbins (2006) suggest that science sequences might consider a focus on the position of chemistry, as it is gradually becoming a prerequisite due to developments in biology. A majority of the schools completed the assessment in grade 10 indicating that biology is placed second in their science sequence. Schools reported a variety of courses that preceded biology in grade 9 although most indicated a physical science course (both chemistry and physics concepts). Given the wide array of course options in high school it may be interesting to investigate the role of the middle school science course sequences as well. Additionally, studies will be needed if the EOC program is expanded to include assessments in other areas of science at the high school level. For the 2014-15 academic year, the state of Missouri is including an optional Physical Science assessment for high schools. It is not known if this assessment will become a permanent portion of the assessment program or not.

Patterns in FRL trends and how they may influence assessment performance might also be considered. Although it was not initially anticipated this study revealed a disturbing pattern regarding the decrease in SES for Missouri Biology students. With little exception all test groups in this study showed an increase in FRL from 2009-13. This indicates there is an increasing student population meeting eligibility guidelines for FRL from which the assessment data is derived. Whether or not the increase in FRL over this time is related to changes in federal guidelines or the downturn in the economy at the time is not known. The USDA establishes the yearly standards for income eligibilities. A review of the federal standards (USDA, 2008; 2012) indicates for a family of four, the 2008-09 annual income poverty level ($21,200) increased each year through the 2012-13 academic year ($23,050). If incomes across Missouri remained consistent from 2009-2013 then federal changes could likely move more households into eligibility. Whether this accounts for the actual FRL changes seen in this study and whether it might have influenced assessment performance has yet to be determined.

Scientific Reasoning. Future studies that measure assessment performance based on scientific reasoning apart from specific science content is recommended. Large-scale assessments such as the ACT and SAT include larger sample sizes and common testing measures that contrast goals specific to one state as focused in this study. Some research has already indicated potential gains not specific to content, but rather inclusive of general scientific reasoning. A case study by Schuchardt, et. al (2008) found significant differences in scientific reasoning scores between Grade 9 PF and Grade 9 biology students. Burgess (2014) reported one school in Alabama had an increase in ACT Science Reasoning scores (from 21.8 in 2010 to 22.9 in 2013) after implementing their PF sequence. He suggests many factors, such as increased opportunities for Advanced Placement electives, new science staff recruitment, appropriate professional development, and curriculum work to align classroom content with standards, may have contributed to these gains. Williams (2009) analyzed student performance data from the ACT measures of College Readiness Standards and the Illinois State Board of Education (ISBE)-Developed Science assessment. The results of three cohorts of students from consecutive graduating classes (2007, 2008, and 2009) indicated there was no significant difference between the study groups and each measure of academic performance in science or mathematics; however, there were significantly higher scientific reasoning gains for students completing the PCB sequence compared to BCP students.

Next Generation Science Standards. With most Americans believing in local control for curriculum and teaching decisions and 58% saying curriculum needs to change (Bushaw & Calderon, 2014b) it may be interesting to measure how the implementation of the Next Generation Science Standards (NGSS Lead States, 2013) will impact future assessment performance for schools with different science course sequences. The structure of these new standards includes three dimensions: Scientific and Engineering Practices (SEP), Disciplinary Core Ideas (DCI), and Cross Cutting Concepts (CCC). A review of NGSS standards shows horizontal articulation to other DCI's in the same grade band as well as vertical alignment across other grades. In regards to the high school life sciences standards, connections to physical science strands are evident in LS1 (From Molecules to Organisms: Structures and Processes) and LS2 (Ecosystems: Interactions, Energy, and Dynamics). Physical science standards connections to LS1 and LS2 include PS1.A (Structure and Properties of Matter), PS1.B (Chemical Reactions), PS3.B (Conservation of Energy and Energy Transfer), and PS3.D (Energy in Chemical Processes). However, standards LS3 (Heredity: Inheritance and Variation of Traits) and LS4 (Biological Evolution: Unity and Diversity) have no connections to standards in the physical sciences. If these become the standards that Missouri bases future assessments in the Biology EOC, the science course sequence may be irrelevant. The apparent lack of

DCI connections between the life and physical sciences in the NGSS mirrors those in the *Atlas* (AAAS, 2001; 2007).

However, if future assessments target the entire performance expectations (SEP, DCI, and CCC) the NGSS portray, as long as prior coursework enables proper development of the SEP and CCC during student learning any influence on performance should be investigated. With the deliberate focus on horizontal as well as vertical alignment it may be possible the NGSS will provide the appropriate connections to make a specific science course sequence more palatable. When, and if, the NGSS become adopted by states the transition to assessments specifically designed to measure these three dimensions will undoubtedly occur. Will science course sequencing influence performance for these assessments, or will the results mirror this study?

Recommendations for School Leaders

Important decisions impacting schools take place regularly. With regards to science curriculum it is usually recommended that Missouri school leaders take into consideration recommendations by professional organizations that seek excellence in their content areas. Although the AAPT (2002) rationale for revising the science course sequence to ensure a PF approach may appear to make sense, the data does not support advocating such a move to improve results in biology. Results indicated Biology EOC PA in Missouri is not affected by any particular high school science sequence (PF or NPF) or grade level. Therefore, when schools are in the process of selecting a high school science sequence, they may wish to consider other factors. Some of these factors may include; 1) how the science sequence fits for whole school scheduling purposes, 2) how the science sequence will prepare their students for success beyond high school given the local/regional career outlook, 3) the funding and availability of resources to support the chosen curricular sequence, 4) the availability and certification of appropriate staff to support implementation of the sequence and curriculum, and 5) the plan for ongoing teacher professional development that will ensure fidelity and implementation success.

Scheduling issues may arise from schools that participate in block scheduling. Stader and Despain (1999) indicated 163 public high schools in Missouri were using some form of block scheduling. According to T. Ogle from Missouri's Department of Elementary and Secondary Education Core Data division, as of 2008 106 high schools were still using some form of block scheduling r. Block scheduling usually allows more opportunities for electives. For example, a school on a typical 7 period day will have a maximum of 28 courses from which students can select required and elective courses. Some block schedules may require as many as 32. If the Missouri requirement for graduation is 24 credits for graduates of 2013 (14 of which are required) this necessitates students taking many electives (as many as 18 for block schedules). The traditional BCP approach does allow for this type of enriched curricular offerings to be available to students seeking further studies in the areas of life science in lower grade levels; however, if a school chooses a PF sequence having enough quality physics teachers to teach those physics electives might be difficult. Physics teacher positions are the most difficult to fill in high schools (Hodapp, et. al, 2009)

The need for the workplace to be equipped with workers competent in the fundamental aspects of their employment is essential to a successful economy. Missouri is a state that shows the life sciences playing a major role in areas of employment. A curriculum rich in the life sciences may likely be more beneficial to the students of the state of Missouri and physics prerequisites may not be substantiated. A recent study by the Missouri Economic Research and Information Center (2004) indicated 13% of Missouri's economy was based upon the life science industry with roughly 2000 different life science companies. From 1990-2000 Missouri witnessed in the Bio-Medical area of the life sciences a 4.1% gain in employment, 12.8% gain in wages, and a 2.8% increase in the number of firms. Research divisions of the life sciences between 1990 and 2000 had a 230% increase in employment, 864% increase in wages, and 80% increase in the number of new business, and workers employed by a life science industry typically received 24% more than statewide pay average.

A report by the Missouri Biotechnology Association (2009) indicated that Missouri allocates 80% of its research funding towards university studies in the life and agricultural sciences. The University of Missouri College of Agriculture - Food and Natural Resources reported more than $63 million in expenditures in 2003, ranking it twelfth among the more than 220 agricultural research institutions in the United States.

With the increased emphasis in the life science industry a curriculum rich in the life sciences would be in order for the students of Missouri. For this to be accomplished students must be given the opportunity to enrich their compulsory science course sequence with viable life science electives. A PF approach in high school may hinder this from becoming a reality as competition for electives begins to occur once required courses have been completed.

Things to Consider

Leaders of science curriculum in schools regularly deal with decisions related to the development and sequence of science courses that align with local, regional, and state standards for performance. In order to maximize student success these decisions must be based upon empirical studies so these decisions meet academic goals. When recommendations to make sweeping changes arise, leaders must weigh these suggestions with skepticism in the absence of data. At the surface, it may appear these recommendations make sense, but education may not operate under simple cause/effect structures. The business of student learning within formal education has numerous variables that may influence outcomes. Understanding the interactions of these fixed effects and interactions through empirical studies is necessary in order to produce academic excellence.

The sequence of high school science courses in the curriculum may continue to be a subject of discussion in the future. The results of this study showing assessment year and socioeconomic status influences biology PA, the lack of influence by grade level and high school science course sequence, the lack of concept connections indicated by important science documents, the continued shortage of competent, high quality, physics teachers, and the shift in economic development would negate the argument for Missouri schools to mandate a PF sequence.

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Appendix A
Missouri Biology Course-Level Expectations (DESE, 2008b)

Key
Strand (Content Discipline)
- Big Idea
  - Concept
    - Assessed Expectation (* Indicates that an item is essential to the curricula of Biology but is not assessed on the Biology EOC. The indicated expectations are taught and assessed locally.)

Strand 1: Properties and Principles of Matter and Energy
- Changes in properties and states of matter provide evidence of the atomic theory of matter
  - Mass is conserved during any physical or chemical change
    - *Compare the mass of the reactants to the mass of the products in a chemical reaction or physical change (e.g., biochemical processes, carbon dioxide-oxygen cycle, nitrogen cycle, decomposition and synthesis reactions involved in a food web) as support for the Law of Conservation of Mass
- Energy has a source, can be stored, and can be transferred but is conserved within a system
  - Energy can be transferred within a system as the total amount of energy remains constant (i.e., Law of Conservation of Energy)
    - *Classify the different ways to store energy (i.e., chemical, nuclear, thermal, mechanical, electromagnetic) and describe the transfer of energy as it changes from kinetic to potential, while the total amount of energy remains constant, within a system (e.g., biochemical processes, carbon dioxide-oxygen cycle, nitrogen cycle, food web)

Strand 2: Properties and Principles of Forces and Motion
- None

Strand 3: Characteristics and Interactions of Living Organisms
- There is a fundamental unity underlying the diversity of all living organisms
  - Organisms progress through life cycles unique to different types of organisms
    - Recognize cells both increase in number and differentiate, becoming specialized in structure and function, during and after embryonic development
    - *Identify factors (e.g., biochemical, temperature) that may affect the differentiation of cells and the development of an organism
  - Cells are the fundamental units of structure and function of all living things
    - * Recognize all organisms are composed of cells, the fundamental units of structure and function
    - Describe the structure of cell parts (e.g., cell wall, cell membrane, cytoplasm, nucleus, chloroplast, mitochondrion, ribosome, vacuole) found in different types of cells (e.g., bacterial, plant, skin, nerve, blood, muscle) and the

functions they perform (e.g., structural support, transport of materials, storage of genetic information, photosynthesis and respiration, synthesis of new molecules, waste disposal) that are necessary to the survival of the cell and organism

- Biological classifications are based on how organisms are related
  - *Explain how similarities used to group taxa might reflect evolutionary relationships (e.g., similarities in DNA and protein structures, internal anatomical features, patterns of development)
  - *Explain how and why the classification of any taxon might change as more is learned about the organisms assigned to that taxon

- Living organisms carry out life processes in order to survive
  - The cell contains a set of structures called organelles that interact to carry out life processes through physical and chemical means
    - *Compare and contrast the structure and function of mitochondria and chloroplasts
    - *Compare and contrast the structure and function of cell wall and cell membranes
    - Explain physical and chemical interactions that occur between organelles (e.g. nucleus, cell membrane, chloroplast, mitochondrion, ribosome) as they carry out life processes
  - Photosynthesis and cellular respiration are complementary processes necessary to the survival of most organisms on Earth
    - Explain the interrelationship between the processes of photosynthesis and cellular respiration (e.g., recycling of oxygen and carbon dioxide), comparing and contrasting photosynthesis and cellular respiration reactions (Do NOT assess intermediate reactions)
    - Determine what factors affect the processes of photosynthesis and cellular respiration (i.e., light intensity, availability of reactants, temperature)
  - Cells carry out chemical transformations that use energy for the synthesis or breakdown of organic compounds
    - Summarize how energy transfer occurs during photosynthesis and cellular respiration as energy is stored in and released from the bonds of chemical compounds (i.e. ATP)
    - *Relate the structure of organic compounds (e.g., proteins, nucleic acids, lipids, carbohydrates) to their role in living systems
    - *Recognize energy is absorbed or released in the breakdown and/or synthesis of organic compounds
    - *Explain how protein enzymes affect chemical reactions (e.g., the breakdown of food molecules, growth and repair, regulation)
    - *Interpret a data table showing the effects of an enzyme on a biochemical reaction
  - Protein structure and function are coded by the DNA (Deoxyribonucleic acid) molecule
    - Explain how the DNA code determines the sequence of amino acids necessary for protein synthesis

    - *Recognize the function of protein in cell structure and function (i.e., enzyme action, growth and repair of body parts, regulation of cell division and differentiation)
  - Cellular activities and responses can maintain stability internally while external conditions are changing (homeostasis)
    - Explain the significance of the selectively permeable membrane to the transport of molecules
    - Predict the movement of molecules across a selectively permeable membrane (i.e., diffusion, osmosis, active transport) needed for a cell to maintain homeostasis given concentration gradients and different sizes of molecules
    - Explain how water is important to cells (e.g., is a buffer for body temperature, provides soluble environment for chemical reactions, serves as a reactant in chemical reactions, provides hydration that maintains cell turgidity, maintains protein shape)
- There is a genetic basis for the transfer of biological characteristics from one generation to the next through reproductive processes
  - Reproduction can occur asexually or sexually
    - *Distinguish between asexual (i.e., binary fission, budding, cloning) and sexual reproduction
  - All living organisms have genetic material (DNA) that carries hereditary information
    - Describe the chemical and structural properties of DNA (e.g., DNA is a large polymer formed from linked subunits of four kinds of nitrogen bases; genetic information is encoded in genes based on the sequence of subunits; each DNA molecule in a cell forms a single chromosome) (Assess the concepts – NOT memorization of nitrogen base pairs)
    - Recognize that DNA codes for proteins, which are expressed as the heritable characteristics of an organism
    - *Recognize that degree of relatedness can be determined by comparing DNA sequences
    - *Explain how an error in the DNA molecule (mutation) can be transferred during replication
    - Identify possible external causes (e.g., heat, radiation, certain chemicals) and effects of DNA mutations (e.g., altered proteins which may affect chemical reactions and structural development)
  - Chromosomes are components of cells that occur in pairs and carry hereditary information from one cell to daughter cells and from parent to offspring during reproduction
    - Recognize the chromosomes of daughter cells, formed through the processes of asexual reproduction and mitosis, the formation of somatic (body) cells in multicellular organisms, are identical to the chromosomes of the parent cell
    - Recognize that during meiosis, the formation of sex cells, chromosomes are reduced to half the number present in the parent cell
    - Explain how fertilization restores the diploid number of chromosomes
    - *Identify the implications of human sex chromosomes for sex determination

- There is heritable variation within every species of organism
  - Describe the advantages and disadvantages of asexual and sexual reproduction with regard to variation within a population
  - *Describe how genes can be altered and combined to create genetic variation within a species (e.g., mutation, recombination of genes)
  - *Recognize that new heritable characteristics can only result from new combinations of existing genes or from mutations of genes in an organism's sex cells
- The pattern of inheritance for many traits can be predicted by using the principles of Mendelian genetics
  - Explain how genotypes (heterozygous and homozygous) contribute to phenotypic variation within a species
  - Predict the probability of the occurrence of specific traits, including sex-linked traits, in an offspring by using a monohybrid cross
  - *Explain how sex-linked traits may or may not result in the expression of a genetic disorder (e.g., hemophilia, muscular dystrophy, color blindness) depending on gender

Strand 4: Changes in Ecosystems and Interactions of Organisms with their Environments

- Organisms are interdependent with one another and with their environment
  - All populations living together within a community interact with one another and with their environment in order to survive and maintain a balanced ecosystem
    - Explain the nature of interactions between organisms in predator/prey relationships and different symbiotic relationships (i.e., mutualism, commensalisms, parasitism)
    - Explain how cooperative (e.g., symbiotic) and competitive (e.g., predator/prey) relationships help maintain balance within an ecosystem
    - *Explain why no two species can occupy the same niche in a community
  - Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite
    - Identify and explain the limiting factors (biotic and abiotic) that may affect the carrying capacity of a population within an ecosystem
    - *Predict how populations within an ecosystem may change in number and/or structure in response to hypothesized changes in biotic and/or abiotic factors
  - All organisms, including humans, and their activities cause changes in their environment that affect the ecosystem
    - *Devise a multi-step plan to restore the stability and/or biodiversity of an ecosystem when given a scenario describing the possible adverse effects of human interactions with that ecosystem (e.g., destruction caused by direct harvesting, pollution, atmospheric changes)
    - *Predict and explain how natural or human caused changes (biological, chemical and/or physical) in one ecosystem may affect other ecosystems due to natural mechanisms (e.g., global wind patterns, water cycle, ocean currents)
  - The diversity of species within an ecosystem is affected by changes in the environment, which can be caused by other organisms or outside processes

    - Predict the impact (beneficial or harmful) a natural or human caused environmental event (e.g., forest fire, flood, volcanic eruption, avalanche, acid rain, global warming, pollution, deforestation, introduction of an exotic species) may have on the diversity of different species in an ecosystem
    - *Describe possible causes of extinction of a population
- Matter and energy flow through the ecosystem
  - As energy flows through the ecosystem, all organisms capture a portion of that energy and transform it to a form they can use
    - *Illustrate and describe the flow of energy within a food web
    - *Explain why there are generally more producers than consumers in an energy pyramid
    - Predict how the use and flow of energy will be altered due to changes in a food web
  - Matter is recycled through an ecosystem
    - *Explain the processes involved in the recycling of nitrogen, oxygen, and carbon through an ecosystem
    - * Explain the importance of the recycling of nitrogen, oxygen, and carbon within an ecosystem
- Genetic variation sorted by the natural selection process explains evidence of biological evolution
  - Evidence for the nature and rates of evolution can be found in anatomical and molecular characteristics of organisms and in the fossil record
    - *Interpret fossil evidence to explain the relatedness of organisms using the principles of superposition and fossil correlation
    - *Evaluate the evidence that supports the theory of biological evolution (e.g., fossil records, similarities between DNA and protein structures, similarities between developmental stages of organisms, homologous and vestigial structures)
  - Reproduction is essential to the continuation of every species
    - *Define a species in terms of the ability to mate and produce fertile offspring
    - Explain the importance of reproduction to the survival of a species (i.e., the failure of a species to reproduce will lead to extinction of that species)
  - Natural selection is the process of sorting individuals based on their ability to survive and reproduce within their ecosystem
    - Identify examples of adaptations that may have resulted from variations favored by natural selection (e.g., long-necked giraffes, long-eared jack rabbits) and describe how that variation may have provided populations an advantage for survival
    - *Explain how genetic homogeneity may cause a population to be more susceptible to extinction (e.g., succumbing to a disease for which there is no natural resistance)
    - Explain how environmental factors (e.g., habitat loss, climate change, pollution, introduction of non-native species) can be agents of natural selection
    - *Given a scenario describing an environmental change, hypothesize why a

given species was unable to survive

Strand 5: Processes and Interactions of the Earth's Systems (Geosphere, Atmosphere, and Hydrosphere

- Human activity is dependent upon and affects Earth's resources and systems
  - Earth's materials are limited natural resources affected by human activity
    - *Predict local and/or global effects of environmental changes when given a scenario describing how the composition of the geosphere, hydrosphere, or atmosphere is altered by natural phenomena or human activities
    - *Recognize how the geomorphology of Missouri (i.e., different types of Missouri soil and rock materials such as limestone, granite, clay, loam; land formations such as Karst (cave) formations, glaciated plains, river channels) affects the survival of organisms

Strand 6: Composition and Structure of the Universe and the Motion of the Objects Within It

- The universe has observable properties and structure
  - The Earth has a composition and location suitable to sustain life
    - * Explain how Earth's environmental characteristics and location in the universe (e.g., atmosphere, temperature, orbital path, magnetic field, mass-gravity, location in solar system) provide a life-supporting environment

Strand 7: Scientific Inquiry

- Science understanding is developed through the use of science process skills, scientific knowledge, scientific investigation, reasoning, and critical thinking
  - Scientific inquiry includes the ability of students to formulate a testable question and explanation, and to select appropriate investigative methods in order to obtain evidence relevant to the explanation
    - Formulate testable questions and hypotheses
    - Analyzing an experiment, identify the components (i.e., independent variable, dependent variables, control of constants, multiple trials) and explain their importance to the design of a valid experiment
    - Design and conduct a valid experiment
    - Recognize it is not always possible, for practical or ethical reasons, to control some conditions (e.g., when sampling or testing humans, when observing animal behaviors in nature)
    - *Acknowledge some scientific explanations (e.g., explanations of astronomical or meteorological phenomena) cannot be tested using a controlled laboratory experiment, but instead by using a model, due to the limits of the laboratory environment, resources, and/or technologies
    - *Acknowledge there is no fixed procedure called "the scientific method", but that some investigations involve systematic observations, carefully collected and relevant evidence, logical reasoning, and some imagination in developing hypotheses and other explanations
    - Evaluate the design of an experiment and make suggestions for reasonable

improvements

- Scientific inquiry relies upon gathering evidence from qualitative and quantitative observations
    - *Make qualitative and quantitative observations using the appropriate senses, tools and equipment to gather data (e.g., microscopes, thermometers, analog and digital meters, computers, spring scales, balances, metric rulers, graduated cylinders)
    - Measure length to the nearest millimeter, mass to the nearest gram, volume to the nearest milliliter, force (weight) to the nearest Newton, temperature to the nearest degree Celsius, time to the nearest second
    - Determine the appropriate tools and techniques to collect, analyze, and interpret data
    - Judge whether measurements and computation of quantities are reasonable
    - Calculate the range, average/mean, percent, and ratios for sets of data
    - *Recognize observation is biased by the experiences and knowledge of the observer (e.g., strong beliefs about what should happen in particular circumstances can prevent the detection of other results)
- Scientific inquiry includes evaluation of explanations (laws/principles, theories/models) in light of evidence (data) and scientific principles (understandings)
    - Use quantitative and qualitative data as support for reasonable explanations (conclusions)
    - Analyze experimental data to determine patterns, relationships, perspectives, and credibility of explanations (e.g., predict/extrapolate data, explain the relationship between the independent and dependent variable)
    - Identify the possible effects of errors in observations, measurements, and calculations, on the validity and reliability of data and resultant explanations (conclusions)
    - Analyze whether evidence (data) and scientific principles support proposed explanations (laws/principles, theories/models)
- The nature of science relies upon communication of results and justification of explanations
    - Communicate the procedures and results of investigations and explanations through oral presentations, drawings and maps, data tables (allowing for the recording and analysis of data relevant to the experiment such as independent and dependent variables, multiple trials, beginning and ending times or temperatures, derived quantities), graphs (bar, single, and multiple line), and equations and writings
    - *Communicate and defend a scientific argument
    - Explain the importance of the public presentation of scientific work and supporting evidence to the scientific community (e.g., work and evidence must be critiqued, reviewed, and validated by peers; needed for subsequent investigations by peers; results can influence the decisions regarding future scientific work)

Strand 8: Impact of Science, Technology and Human Activity

- The nature of technology can advance, and is advanced by, science as it seeks to apply scientific knowledge in ways that meet human needs
  - Advances in technology often result in improved data collection and an increase in scientific information
    - * Recognize the relationships linking technology and science (e.g., how technological problems may create a demand for new science knowledge, how new technologies make it possible for scientists to extend research and advance science)
- Historical and cultural perspectives of scientific explanations help to improve understanding of the nature of science and how science knowledge and technology evolve over time
  - People of different gender and ethnicity have contributed to scientific discoveries and the invention of technological innovations
    - *Recognize contributions to science are not limited to the work of one particular group, but are made by a diverse group of scientists representing various ethnic and gender groups
    - *Recognize gender and ethnicity of scientists often influence the questions asked and/or the methods used in scientific research and may limit or advance science knowledge and/or technology
  - Scientific theories are developed based on the body of knowledge that exists at any particular time and must be rigorously questioned and tested for validity
    - *Identify and describe how explanations (laws/principles, theories/models) of scientific phenomena have changed over time as a result of new evidence (e.g., cell theory, theories of spontaneous generation and biogenesis, theories of extinction, evolution theory, structure of the cell membrane, genetic theory of inheritance)
    - *Identify and analyze current theories that are being questioned, and compare them to new theories that have emerged to challenge older ones (e.g., theories of evolution, extinction, global warming)
- Science and technology affect, and are affected by, society
  - Social, political, economic, ethical and environmental factors strongly influence, and are influenced by, the direction of progress of science and technology
    - *Analyze the roles of science and society as they interact to determine the direction of scientific and technological progress (e.g., prioritization of and funding for new scientific research and technological development is determined on the basis of individual, political and social values and needs; understanding basic concepts and principles of science and technology influences debate about the economics, policies, politics, and ethics of various scientific and technological challenges)
    - *Identify and describe major scientific and technological challenges to society and their ramifications for public policy (e.g., global warming, limitations to fossil fuels, genetic engineering of plants, space and/or medical research)
    - *Analyze and evaluate the drawbacks (e.g., design constraints, unintended consequences, risks), benefits, and factors (i.e., social, political, economic,

ethical, and environmental) affecting progress toward meeting major scientific and technological challenges (e.g., limitations placed on stem-cell research or genetic engineering, introduction of alien species, deforestation, bioterrorism, nuclear energy, genetic counseling, use of alternative energies for carbon fuels, use of pesticides

- Scientific ethics require that scientists must not knowingly subject people or the community to health or property risks without their knowledge and consent
    - *Identify and evaluate the need for informed consent in experimentation
    - *Identify the ethical issues involved in experimentation (i.e., risks to organisms or environment)
    - *Identify and evaluate the role of models as an ethical alternative to direct experimentation (e.g., using a model for a stream rather than pouring oil in an existing stream when studying the effects of oil pollution on aquatic plants)
- Scientific information is presented through a number of credible sources, but is at times influenced in such a way to become non-credible
    - *Evaluate a given source for its scientific credibility (e.g., articles in a new periodical quoting an "eye witness", a scientist speaking within or outside his/her area of expertise)
    - *Explain why accurate record-keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society

Appendix B
Graphical Representations of YR and SES Variables

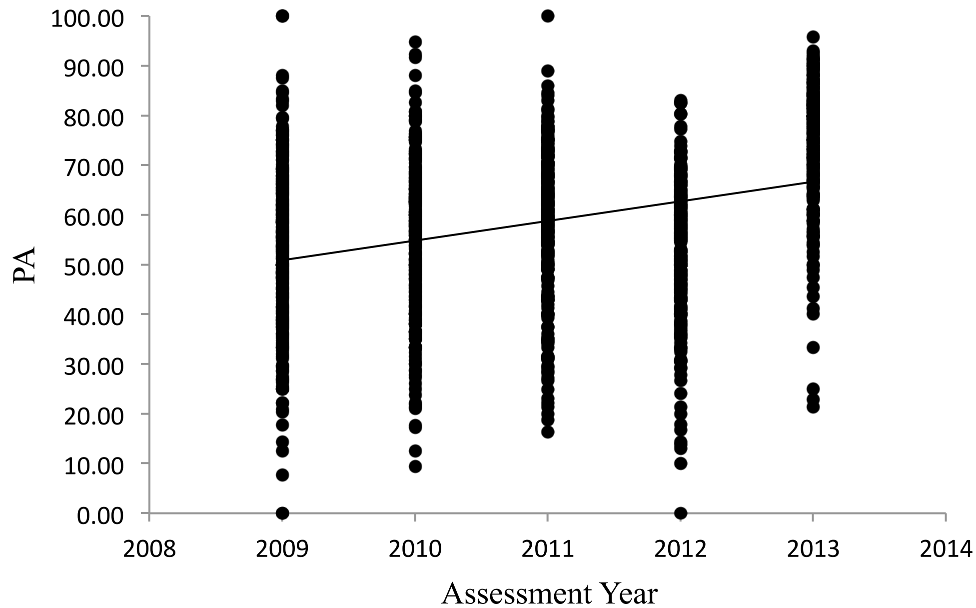

Figure B1. Change in assessment performance (PA) for 2009-2013 assessment years.

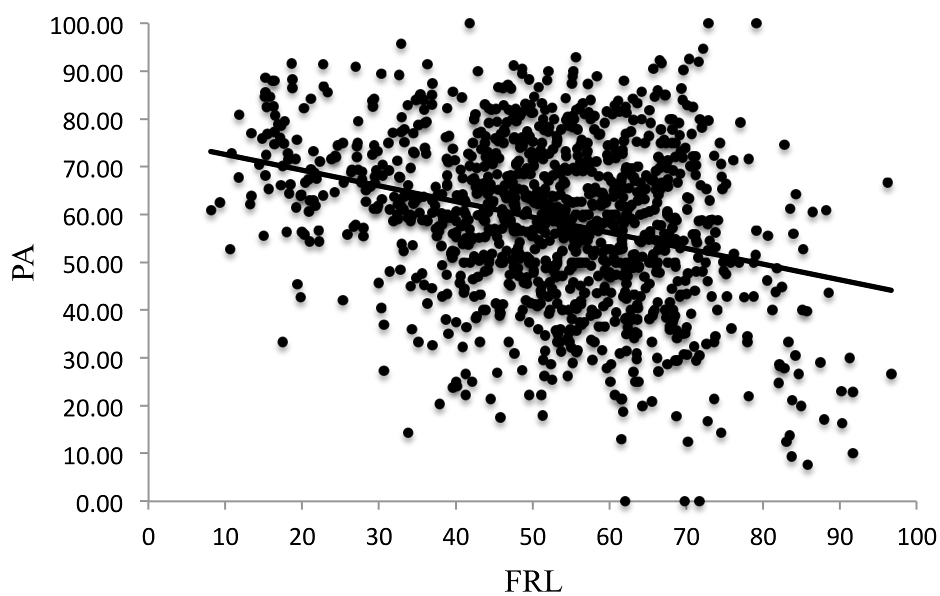

Figure B2. Relationship between socioeconomic status (FRL) and assessment performance (PA).

VITA

Jay Lee Meyers was born August 25, 1966 to William (Bill) and Judith (Judy) Meyers in Hiawatha, KS. He attended elementary school in Stanberry, MO, and junior and senior high school in Savannah, MO where he graduated in 1984.

Jay completed his undergraduate studies at Missouri Western State College in 1988 obtaining a Bachelor of Science in Biology with Chemistry minor. Additionally, he obtained lifetime teaching certifications in Biology (Grades 7-12) and Chemistry (Grades 7-12). In 1999 he completed his Masters of Science in Science Education through Northwest Missouri State University. He began his doctoral studies in science education at the University of Missouri in Columbia, MO in 2008.

Jay's first teaching position was as a science teacher with the King City R-I Schools in 1988 for a teacher who was on leave for one year. The next year he taught science at Dekalb High School for the Buchanan County R-IV School District, and subsequently returned to King City where he served as a science teacher, coach, and class sponsor from 1990-1995. Since 1995, Jay has been employed as a science teacher at Central High School in St. Joseph, MO for the St. Joseph School District, and since 1999 he has been the District Secondary Science Coordinator. In 2004 Jay was the first teacher in the St. Joseph School District to complete National Board Certification obtaining certification in Adolescent and Young Adulthood Science with an emphasis in Biology, and subsequently renewed this certification in 2014. Jay has also served as adjunct science education faculty for Northwest Missouri State University, adjunct biology faculty Missouri Western State University, and as the Dual Credit Biology liaison for the Western Institute at Missouri Western State University.

Throughout his career in teaching Jay has served on several committees for the State of Missouri in the areas of assessment (table leader for scoring, bias and content review, and level setting) as well as science model lesson review. He is a member of several, science teaching organizations both at the state and national level.

Throughout his doctoral studies Jay maintained his full time teaching and curriculum coordinator responsibilities, presented workshops at state and regional conferences, and led professional development in the areas of inquiry, educational technology, digital data collection, scientific explanations, and scientific argumentation.

Jay has received the following honors and awards: 2009 Presidential Award for Excellence in Math and Science Teaching (Missouri Finalist), 2008 Missouri Outstanding Biology Teacher Award from the National Association of Biology Teachers, 2005 Monsanto Science Teaching Award from the Junior Science, Engineering, and Humanities Symposium, 2001 Sponsoring Teacher Award from the Junior Science Engineering and Humanities Symposium, and the 1994 Outstanding Science Teacher Award from the Missouri Academy of Science.

Jay's career goal is to focus on pre and in-service science teacher education after he retires from public school service.