Exploring Teacher Determinants and Student Outcomes of Inquiry Use in a Nanoscience Intervention

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
August 1, 2015

Keywords: intervention, inquiry, evaluation, science, Alabama, middle school

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Abstract

Since the release of the new science education standards, there has been a greater emphasis on incorporating inquiry-based teaching in the classroom. The utilization of inquiry methods enables scientists to gain in-depth knowledge of specific domains through analysis, interpretation and evaluation. Inquiry-based instruction incorporates these practices into classroom instruction allowing students to develop these skills and craft conclusions based on research and data. In response to this call for inquiry-based teaching, several federally funded initiatives have been introduced to support teacher need to adapt curriculum materials to foster student learning through inquiry-based practice (U.S. Department of Education, 2014). The intervention from which this study is based is one of such initiatives.

The intent behind this initiative is to raise both student and teacher knowledge and attitudes towards science through the use of inquiry based modules in the classroom. However assumptions related to this project include: teachers know what is meant by inquiry, teachers know how to implement inquiry in the classroom, and the modules are, in fact, inquiry based. Thus, the purpose of this study is to: a) examine the extent to which teachers promote inquiry through classroom instruction and assignments; b) how this instruction impacts student achievement, and c) examine the effects of teacher beliefs and pedagogical content knowledge on the use of inquiry-based instruction.

The findings indicate that these science teachers do understand the *importance* of science and they do place a high value on using inquiry strategies to facilitate student learning. However, there are some misconceptions and misunderstandings regarding the enactment of inquiry practices in the classroom. Although teachers in this study believe they are implementing these strategies during their

lessons, a close examination of lesson plans and classroom observations indicated a narrow use of inquiry in the classroom. Teachers may believe they are conducting inquiry-based lessons, however they are lacking key components. Since the use of inquiry is pinnacle to the intervention, it is critical that teachers use these methods successfully in order to implement modules with fidelity.

Acknowledgments

My deepest appreciation and thanks are given to Dr. David Shannon, my committee chair, whose unwavering support, guidance, and encouragement has been invaluable. To my committee members, Drs. Joni Lakin, Margaret Ross, and Jill Salisbury-Glennon, who dedicated their time and patience throughout the development and execution of this study. Also, to my outside reader, Dr. Christine Schnittka, who provided invaluable guidance and knowledge that contributed significantly to the quality of my study.

Words cannot begin to express my gratitude, love, and appreciation for my parents, Alisa and David Smith, and my siblings, Mariah and Dante Smith. Their unconditional love and support throughout my life gave me the courage, perseverance, and ambition to set goals and complete them with integrity to the very best of my ability. My mother has molded me into the woman I am today and I am forever grateful for her. I know without her sacrifices, there is no way I would where I am today. Thank you for providing me with everything I needed to become successful. I love you.

I would also like to thank my best friend/sister, Erica Kenner, for her constant support and reassurance. We became best friends in 2004 and have grown closer and closer over the years and I am truly blessed to have her by my side! To my newest best friends/family, Leo, Alana, and Derrick, I am so appreciative for your friendship and understanding. No matter what, you were always there when I needed you and amazing people like you are hard to find. I love each of you very much. To Jason, Lisa, and Beatrice (Mimi) Breaux, you all have helped me, supported me, listened to my rants, and doggy-sat my furry child countless times over the years! Your support helped me focus and get through this challenging chapter in my life. I really can’t express how grateful I am for you both, love y’all!

Lastly to my family and friends that I could not name. Each of you are so important to me and I wish I had the time and space here to fully express my gratitude. This has been one of the most challenging, yet rewarding, experiences in my life and I know that without each of you, I would not have had the strength or determination to get through it. Thank you all.

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List of Abbreviations

5E	Engage, Explore, Explain, Elaborate, Evaluate Instructional Model
5E ILPv2	5E Inquiry Lesson Plan Rubric version 2
AIS	Teacher Inquiry Scales
IS	Student Rated Teacher Inquiry Strategies
MSP	Math and Science Partnership
NRC	National Research Council
NSES	National Science Education Standards
P-SOP	Practices of Science Observation Protocol
PB	Perceived Benefit
PN	Perceived Need
SAT-10	Stanford Achievement Test 10th Edition

CHAPTER I: INTRODUCTION

Since 2001, the No Child Left Behind (NCLB) Act has attempted to reform the educational paradigm to insure the sustainability of America's economy and work force in the 21st Century. The foundational principles regarding this act shifted the accountability for student achievement heavily on to teachers and other school leaders. To measure student achievement and to quantify academic gains, standardized tests became the staple unit of analysis (Phelps, 2012). The call for the enhancement of test scores resulted in an influx of high-stakes testing in order to gauge the knowledge gains of students in core subject areas. Subsequently, teachers began "teaching to the test," thus sacrificing utilization of complex assignments in tandem with high cognitive content to support and develop higher-order thinking skills (Valli, Croninger, Alexander, Chambliss, Graeber, & Price, 2004).

More recently, the blueprint for the reform of the Elementary and Secondary Education Act (formerly NCLB), has called for the reform the educational system in order to prepare students to be active and effective contributors to society (U.S. Department of Education, 2010). Specifically, science education has been at the pinnacle of these reform efforts. Equipping students with the skills required to be active contributors in the exponentially growing field of science is imperative. The blueprint stated, "Students need a well-rounded education [in order] to contribute as citizens in our democracy and to thrive in a global economy…" (U.S. Department of Education, 2011, p.4). The blueprint outlined federal governmental support regarding effective teachers and school leaders, equity in educational opportunities for all children, and innovative improvement efforts in order to adequately prepare students to use higher order thinking skills. Although the blueprint outlined several supports and initiatives the government would like to see regarding education, there were no steps or guidance as to how or what this reform should look like. The ambiguity regarding the reform leaves decisions to local and state districts about how to improve education. Reformers suggest that experiences within the classroom should mirror practices of actual scientists (American Association for the Advancement of Science, 1993; Bybee, 2009; National Research Council, 2012; National Research Council, 2013).

Teachers need to utilize inquiry-based, student centered instructional practices that provide students with the opportunity to enhance higher order thinking skills and facilitate in the construction of knowledge (AAAS, 1993; National Research Council, 1996, 2006; Schneider, Krajcik, & Marx, 2000). Historically, professional development regarding the improvement of instruction has often centered on specific strategies, both didactic and constructivist (Corcoran, 1995). However, regardless of curriculum design, the quality of instruction is critical. In order to create an environment conducive to producing students with the skills necessary to be successful contributors to society in the 21st century, educational reform must focus on both appropriate curriculum and quality instruction.

Overview of the Problem

Nationally, the focus on Science, Technology, Engineering, and Math (STEM) education, has been on the forefront of the nation's educational agenda (National Governors Association Center for Best Practices, 2011). By 2018, there will be over 8 million jobs in STEM fields that need to be filled (Alliance for Teaching and Technology, 2013). According to the Bureau of Labor Statistics (2010), filling jobs related to science will be exceedingly difficult due to employee withdrawal coupled with the decrease of student achievement and interest related to science. Each year, the Programme for International Assessment (PISA) administers an assessment to determine how and to what extent students between the ages fifteen and sixteen years old understand and apply what they have learned in science, mathematics, and reading (PISA, 2012). Out of 65 countries that participated in this assessment in 2012, students in the United States ranked 28th in Science and 36th in Math (PISA, 2012). Although the United States scores for Math and Science were average for 2012 (PISA, 2012), there is evidence of the need to improve in order to reach the goal of producing some of the best-educated workers in the world (AAAS, 1993). Globally, with the increased use of mobile technology (Lu, Yao, & Yu, 2005), computers (Carson, Pickett, & Janssen, 2011), and the need for innovative solutions to societal issues such as disease and global warming (Adkins, 2012), there is an increasing dependence on science and technology. Compared to the other economically advantaged countries, the primary and secondary educational systems in the United States are not producing enough students to succeed in science and technology fields (National Academy of Sciences, 2006).

There have been numerous reform efforts focused on increasing achievement in science through the reconstruction of classrooms to reflect real world experiences related to science. Even though there has been a concentrated focus on inquiry, there is little guidance on specifically how these classrooms should be restructured to incorporate inquiry (AAAS, 1993; NRC, 2013; Carnegie Corporation of New York & the Institute for Advanced Study, 2007). This issue is magnified by the varying definitions and perspectives regarding inquiry held by primary and secondary education teachers (NRC, 2013). Specifically, the most prevalent method of instruction in science centers on covering a vast breadth of information resulting in didactic interactions and the inability to apply this information outside of the classroom (Lee, Grigg, and Donahue, 2007; ETS 2009). Lave and Wenger (1991) proposed that learning should take place in the same context in which it is applied with a concentrated focus on construction of knowledge through social interaction. Therefore, classrooms should reflect the environment of the topic being taught as learning is a function of the activity and culture in which it occurs (Lave, 1988). For example, activities such as on the job training, service learning, and even role playing can be viewed as pedagogical strategies for situated learning as they provide students with authentic learning experiences in the context which the skills acquired during training will be utilized. Students utilize contextual clues when learning new information, which allow knowledge to be readily accessible in the future (Schank, 1995). However, if the situation in which the knowledge is obtained is too specific (Edelson, 1997) or does not accurately reflect the context in which it would be used in the real world (Brown, Collins, & Duguid, 1989), students may have knowledge regarding a specific topic but lack knowing when and how to apply that knowledge.

According to Newmann (1988), didactic instruction is not adequately preparing students for beyond school or engaging students to pursue careers related to science. The foundational principle of science is the utilization of inquiry and exploration to build and organize knowledge. It is through inquiry that scientists gain in-depth knowledge of specific domains through analysis, interpretation and evaluation. Students need to develop scientific knowledge as well as apply this knowledge in an environment conducive to developing analytical, critical, and deep thinking skills. This type of learning is created and supported by high quality instruction that is relevant to students and useful beyond school.

Study Purpose

One goal of science education rests in supplying well-trained research and clinical investigators in order to support the demand for these careers in the 21st century. However, recent criticisms suggest the current environment in most science classrooms does not reflect real-word experiences related to science. Specifically, the most prevalent method of instruction centers on covering a vast breadth of information resulting in didactic interactions and the inability to apply this information outside of the classroom (Lee et al., 2007; ETS 2009). Since the release of the science education standards (AAAS, 1993; NGAA, 2013; NRC, 2012), there has been a greater emphasis on incorporating inquiry-based teaching in the classroom. The utilization of inquiry methods enables scientists to gain in-depth knowledge of specific domains and answer scientific questions through analysis, interpretation and evaluation. Inquiry-based instruction incorporates these practices into classroom instruction allowing students to develop these skills and craft conclusions based on research and data analysis. In response to this call for inquiry-based teaching, several federally funded initiatives have been introduced to support the teacher need to adapt curriculum materials to foster student learning through inquiry-based practice (U.S. Department of Education, 2014).

The intervention from which this study is based is one such initiative. Teachers are challenged with implementing inquiry-based science education modules that are designed by researchers, engineers, and pre and in-service teachers. The intent behind this initiative is to raise both student and teacher knowledge and attitudes towards science through the use of inquiry-based modules in the classroom. Teachers are afforded local and regional professional development opportunities each year to a) learn about new modules and b) participate in a hands-on demonstration of select modules based on grade level. However, it is important to note that there are several assumptions related to this project:

A. Teachers understand what is meant by inquiry,

B. Teachers know how to implement inquiry in the classroom, and

C. The modules that are given to teachers are, in fact, inquiry based.

Thus, the purpose of this study is to examine the assumptions by: a) examining the extent to which teachers promote inquiry through classroom instruction, b) the extent to which instruction actually impacts student achievement, and c) the effects of teacher beliefs and attitudes on the use of inquiry-based instruction.

Research Questions

1. To what extent does inquiry use vary in the creation of a module versus a non-module[1] lesson?

[1] Non-module refers to lesson plans created by teacher participants. Teachers submitted lesson plans they believed were inquiry-based.

2. Do teachers who use modules demonstrate higher levels of inquiry planning and have higher achieving students?
3. What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?

Study Significance

This study added to the literature regarding the need to promote inquiry-based learning in the classroom and specific teacher characteristics that are critical factors for effective inquiry use in the classroom. Effective inquiry use by teachers requires certain characteristics related to knowledge and planning. The heart of inquiry lies in authentic questioning, data collection, and analysis. Therefore, there are some techniques that can be taught or developed to promote inquiry, however, in order to promote inquiry efficiently, looking at specific teacher characteristics such as attitudes and lesson plan design may be more critical.

This study also begins to address questions regarding intervention readiness in relation to inquiry-based modules in lessons. Previous research regarding health support and bullying prevention interventions has shown that provider characteristics are critical to the successful implementation of an intervention (e.g. Kallestad & Olewus, 2003; Durlak & Dupre, 2008). Particularly, provider (teacher) characteristics that are instrumental in intervention implementation are perceptions related to the need for and benefits of the intervention, and skill proficiency. Providers who recognize a specific need for innovation and believe the innovation will produce desired benefits, who feel more confident in their ability to do what is expected , and have the requisite skills, are more likely to implement a program at higher levels of dosage or fidelity (Kallestad and Olewus, 2003). With growing emphasis placed on inquiry-based interventions, extending the literature on influential factors regarding such programs will expand existing knowledge for such interventions as well as provide insight on increasing sustainability.

CHAPTER II: REVIEW OF LITERATURE

THEORETICAL FOUNDATIONS

Learning theory

The foundational principles guiding instruction in classrooms have predominately rested in behaviorism (traditional teaching) and constructivism. Often, traditional teaching techniques are employed with lower-level, factual knowledge. However, there has been a paradigm shift and a supporting research base advocating the utilization of more constructivist approaches, especially in science education (Lord, 1994; Tobin, 1993; Harlen, 1999). According to constructivist principles, building knowledge through authentic tasks by asking questions and conjuring alternative solutions is the best way for students to gain higher order knowledge. Constructivist theory elucidates the nature of the learner as one who self-directs authentic constructs of knowledge through assimilation with previous knowledge (Dewey, 1929; Kliebard, 1992). Therefore, the theoretical framework for this investigation is affixed in the constructivist conviction that meaningful knowledge is built through a process where learners develop their understandings, which are related to and based on real world experiences.

Behaviorism

According to behaviorism, a traditional learning theory, behavior is defined as an individual's response to their environment. Changes in response are the result of stimuli and changes in behavior are the result of stimulus-response associations (Parkay & Hass, 2000). Individuals subsequently choose their desired response to stimuli based on prior experiences, thus resulting in perpetual behavior. Behaviorists, such as Ivan Pavlov, John Watson, and B.F. Skinner, defined learning as a behavior (Bolles, 1979). Since learning is a behavior, it could be tailored (or shaped) by using different types of reinforcers (or consequences). Traditionally, behavioristic methods of teaching prepare students to quickly and accurately reproduce knowledge that was created by others. Typically, the utilization of worksheets and textbooks served as the primary as tools for instruction. For example, an instructor holds up flashcards with dates or names and expects students to respond with the answer automatically or timed multiplication assessments where students are given an arbitrary amount of time (i.e. two minutes) to answer one hundred multiplication questions. Instructors are able to instill simple pairings by using tools such as flashcards in order to teach simple knowledge content, which is especially useful in lower-order thinking. By using this method of instruction to teach basic concepts, a solid foundation contributing to the support of higher-level thinking (such as problem solving, synthesis, and analysis) is built (Bloom, Englehart, Furst, Hill, Krathwohl, 1956).

Behaviorism is based heavily on changes in observable behavior, therefore it is typically most effective within contexts that require a high level of structure or addresses maladaptive problem behaviors that are common with individuals with developmental disabilities, behavioral disorders, and educational disabilities (O'Neill, Horner, Albin, Sprague, Storey, & Newton, 1997; Greer, 1994). One form of behaviorist teaching, Direct Instruction, has been studied for several years and advocates for this method propose it produces superior results when compared to other forms of instruction (Adams & Carnine, 2003). Direct Instruction is a systematic, scripted form of instruction emphasizing lessons that are fast paced and sequenced. This type of instruction is anchored in teacher modeling, group response, and some individual practice. An additional approach to traditional learning is the utilization of drill and practice tutorials (Shield, 2000). Students are able to master technical terms, descriptions, and processes through structured lessons that provide immediate feedback. With these traditional approaches to instruction, the classroom becomes teacher-centered and the concept of the "passive-student" is introduced (Hake, 1998, p.54). Instructional time is lecture based where the teacher provides information such as charts, diagrams, and other factual or concrete knowledge. These types of knowledge are critical components on which higher order processes such as problem solving, communication, creativity, and overall competency are built. In order to effectively produce meaning related to this lower-level knowledge students must be able to construct meaning based on prior knowledge, which is the premise of the constructivist theory of learning.

Constructivism

Students enter school with diverse ways of thinking about science based on their experiences with their environment. Based on these experiences, students create their own sophisticated ways of processing information and experiences (Bruner, 1961). They gain further scientific knowledge in the classroom through opportunities to participate in various scientific practices such as exploring new concepts, posing questions, collecting evidence and data, and refining concepts (NRC, 2012). Students are constantly building and refining knowledge not only through educational experiences, but also through social interaction (Vygotsky, 1934). Constructivist theorists believe that knowledge is constructed through experience and reflection. In order to construct knowledge, individuals must ask questions, explore, and assess in order to be active creators of their own knowledge (Jones & Brader-Araje, 2002). In education, instruction anchored in constructivism tends to utilize techniques such as experiments and hands-on activities in order to foster the creation of new knowledge or mold existing knowledge. Effective constructivist teachers understand students' preconceptions, and therefore guide activities and dialogue to facilitate their understanding, and allow students to support or revise theories based on scientific procedures (e.g. collecting, analyzing, and interpreting data) (Polman & Pea, 2001). For example, the instructor may begin with posing a problem that needs to be solved, followed by asking students their opinions about how to solve this problem, subsequently testing each of their hypotheses. Schnittka (2009) has developed a series of lessons that incorporate each of these elements. One of the better noted of these lessons is entitled Save the Penguins. The instructor beings the lesson by explaining how penguins are losing their homes due to global warming which is followed by an explanation of heat conduction, convection, and radiation. Lastly, students are posed the task of building a penguin house that will “save” their ice penguin from melting. Students test the insulative properties of several materials (e.g. Mylar, aluminum, wool, etc.) and then building their penguin house using the materials they believe will keep their penguin cold. Students are actively creating their understanding through exploration and experimentation. The instructor allows students to conjure and test hypotheses before reflecting and discussing solutions that were both successful and unsuccessful. Instruction centering on constructivism prioritizes learning through the construction of meaning. This requires the learner to actively engage in the meaning-making processes, which opposes the traditional-behavioristic view of the teaching and learning process (von Glasserfield, 1995).

A critical underlying tenet of this theory is that students learn how to learn though exploration, experimentation, and communication. Piaget (1970) states that knowledge gaining and meaning making are evolving processes involving actively assimilating and accommodating new experiences with previous knowledge and prior understanding. Therefore, the instructor’s role becomes more facilitative through mediation and prompting. By asking thought-provoking questions, students are able to assess and develop their understanding of a specific domain. A critical distinction between traditional and constructivist classrooms lies within the realm of the instructor’s role (Staver, 1998). In constructivist classrooms, knowledge is not gained through the rote memorization of facts and processes, but as an evolving and ever changing cycle of building upon and refining existing knowledge (see Table 1). This process of obtaining knowledge is commonly referred to as higher order thinking and aligns with processes typically utilized by scientists (Newmann, 1993; Domin, 1999; Mastropeiri, Scruggs, Norland, Berkley, McDugffie, & Tornquist, 2006).

Table 1. Traditional Versus Constructivist Teaching Orientations

Traditional Classroom	**Constructivist Classroom**

Curriculum begins with parts of the whole and emphasizes basic skills.	Curriculum emphasizes big concepts, beginning with the whole and expanding to include the parts.
Strict adherence to fixed curriculum is highly valued.	Pursuit of student questions and interests is valued.
Materials are primarily textbooks and workbooks.	Materials include primary sources and manipulative material.
Learning is based on repetition.	Learning is interactive, building on what the student already knows.
Teachers disseminated information to students. Students become passive recipients of knowledge.	Teachers have a dialogue with students, helping students to construct their own knowledge.
Teacher's role is directive, rooted in authority.	Teacher's role is interactive, rooted in negotiation.
Assessment is through testing, correct answers.	Assessment includes student works, observations, and points of view, as well as tests. Process is as important as product.
Knowledge is seen as inert.	Knowledge is seen as dynamic, ever changing with our experiences.
Students work primarily alone.	Students work primarily in groups.

(Wilson, Liepolt, & Rahman, 2013)

Scientific Inquiry

"If you have doubts about how learning happens, engage in sustained inquiry: study, ponder, consider alternative possibilities and arrive at your belief grounded in evidence. Inquiry is a key part of constructivist learning." John Dewey (Dewey, 1929)

According to the National Science Education Standards (National Research Council, 2000), scientific inquiry is defined as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists would study the natural world," (pg. 23). Teaching students how to do science and construct knowledge through the processes and practices utilized by scientists is a goal of science education (National Research Council, 2006; American Association for the Advancement of Science, 1993). The utilization of inquiry-based methods such as asking questions, investigations, and collecting and analyzing data allows students to discover answers to their questions (Wilson et al., 2013). According to Bell, Smetana, and Binns (2005), although hands-on activities can be a useful pedagogical tool, an activity is inquiry-based only a) there is a research question and b) that research question is answerable through data analysis. However, constructing knowledge alone is inadequate in the preparation of students. Simply constructing new knowledge does not justify its accuracy nor does it warrant its validity or viability of being adequately applicable to individual and social contexts (Von Glasserfield, 1992). In order for the construction of knowledge to be significant, it should be grounded in disciplined inquiry meaning that students are building on prior knowledge to gain more in-depth knowledge of scientific problems, and expressing ideas and findings through various forms of communication (i.e. discussions, research papers, graphical displays, etc.) (Authentic Intellectual Work, 2013; Newmann, 1988; Scheurman & Newmann, 1998). According the Center for Authentic Intellectual Work (2013), disciplined inquiry includes utilization of a prior knowledge base, in-depth understanding of a topic as opposed to superficial awareness, and the expression of ideas and conclusions through communication. Thus, working with others and sharing ideas allows us to check the viability of these ideas. Through this process we support creative thinking and learn which ideas are valuable in specific contexts.

The use of inquiry methods in classrooms is widely supported by researchers and educators due to the utilization of processes that allow students to mirror the mental and physical behaviors of scientists (Willoughby, 2005; National Research Council, 2006). Students must use existing knowledge in tandem with scientific reasoning and critical thinking in order to develop and expand existing knowledge (National Research Council, 2012). Compared to traditional methods of instruction, research has consistently demonstrated that students who are taught using inquiry-based methods are higher achieving in terms of academic competency and attitudes towards science (Minner, Levy, and Century, 2010; Prince, 2004; Selim and Shrigley, 1983). To be specific, a study conducted by Chang and Mao

(1998) compared the impact of traditional based instruction versus inquiry based instruction over the course of two weeks. Results of this study indicated that students that were taught using inquiry based methods scored significantly higher on achievement tests than students who were taught utilizing the more didactic approach.

Historically, there have been several approaches attempting to discover the perfect elixir to constructing scientific knowledge. Although not always practical to utilize every day, science instruction should employ inquiry methods that mirror the way science is practiced in the real world. DeBoer (2000) argues science literacy should not focus on specific outcomes, but rather goals relatable to the instructor and their students' situations through concepts and methodologies most conducive for their students. When using inquiry to evaluate scientific knowledge, instructors challenge students and pose questions such as "what data do we keep and which do we discard," "what patterns exist in the data,"" what explanations account for the patterns,"" Is one explanation better than another?" (NRC, 2012). Students are required to draw on evidence and employ analytical skills to determine the vitality of their claims. Through these processes, students are utilizing skills congruent with those of real-world scientists and igniting appreciation and gaining a genuine understanding of science.

GAINING MEANING FROM INSTRUCTION

In order for students to gain meaning from instruction, students must be able to effectively align information in a cohesive manner. Often, students are presented with fragmented pieces of information that are disconnected, and therefore have very little meaning or relevance to each student. Although this anomaly has been well documented in traditional classrooms (Bayraktar, 2002; Chang and Mao, 1999), this can also be apparent when constructivist methods are implemented (Newmann, Marks, & Gamoran, 1996). Authentic pedagogy is instruction and assessment aimed at promoting intellectual achievements and accomplishments that are meaningful and comparable to those seen by adults in the real world (Newmann, 1993; Newmann & Wehlage, 1993; Newmann et al., 1996). Inquiry develops skills related to questioning, data gathering, and synthesis that lead to an informed conclusion. Thus, the use of inquiry practices goes beyond the ability to perform well on a test, it involves successful application of knowledge in tandem with the essential thought processes (critical thinking and problem solving) when confronted with issues (Scheurman & Newmann, 1998).

In examining various types of intellectual challenges faced by adults, Newmann, King, and Carmichael (2007) conclude that adults typically apply previous knowledge in order to construct and develop solutions to new problems. Although knowledge of basic facts, processes, and theories are important, being able to combine and apply this knowledge in novel contexts is critical. Therefore, classroom instruction should be grounded primarily in rich intellectual experiences rather than the memorization and regurgitation of rudimentary information. Newmann and associates (1996) advocate that constructing knowledge through inquiry coupled with elaborated communication are the foundational principles of meaningful, high-quality instruction.

As a residual effect of the accountability standards and emphasis on standardized testing, achievement in the current educational system is operationalized as grades and scores on achievement tests (Phelps, 2012). As a result, school curriculum tends to focus on "superficial exposure" to a number of fragmented topics with minimal explicit connection to life beyond school hours (Newmann & associates, 1996). In order to fill the millions of jobs related to science, students need to be equipped with essential intellectual qualities. For example, consider the processes related to building a severe weather alert system that can issue accurate warnings thirty minutes faster than existing systems. When developing the system, an atmospheric scientist or meteorologist has to rely on previous knowledge regarding design and construction of existing models, how weather systems work, and most importantly, ways to identify characteristics in the atmosphere that may substantially contribute to the formation of severe weather patterns. This foundational knowledge will aid in solving rudimentary problems that may occur; however, unique problems will require the construction of new processes to address these issues. These issues may be related to functionality or design and may require the application of disciplined knowledge that has been accumulated from science, technology, and math. The successful completion of constructing the new alert system requires and showcases the use of the essential intellectual qualities that define authentic achievement. Thus, authentic achievement, as operationalized by this model, is the “intellectual accomplishments that are worthwhile, significant, and meaningful, such as those undertaken by successful adults…” (Newmann, 1996, p. 23).

Implications regarding classroom instruction and relevance to future choices are the driving forces behind educational reform in science classrooms. Practical applications and techniques are critical in order to positively affect learning. Higher utilization of inquiry practices is positively correlated with higher achievement on mandated-state tests (Lee, Smith, & Croninger, 1997; Newmann, Bryk, & Nagaoka, 2001). Higher achievement is also linked to higher levels of deep knowledge and higher order thinking (Schneider, Kraijick, Marx, Soloway, 2002). Research suggests that that the development of skills related to higher order thinking is more valuable than the lower level knowledge that tends to take precedence in schools in order to prepare for high stakes exams (Messick, 1994; Linn, 2001). Often these exams focus on lower level knowledge and have no relation to the state mandated standards in their respective field. Therefore, this model that focuses on quality instruction, which advocates the proper utilization of instructional methods within a context, is conducive to fostering the skills required to be successful academically and beyond matriculation.

Inquiry and the 5 E Instructional Model

The National Science Education Standards (NRC, 1996) outline three goals for all science education students: 1) to learn important principles and concepts of science, 2) to develop the procedural skills and critical reasoning skills needed to carry out scientific investigations and, 3) to understand the nature of science as a human activity and a way of constructing knowledge (CIRES, 2013). These goals elucidate the critical need for students to learn and understand the process of building and creating new knowledge that mirrors strategies used by scientists. According to the National Science Education Standards (NRC, 2012), "scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity," (p.1). Also, the National Science Education Standards emphasize the indicators of scientific literacy that are aligned with foundational principles of inquiry. Thus, students will need to "develop deep knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.," (NRC, 2012, p.2). Although not practical to utilize every day, inquiry learning in the classroom allows students the opportunity to develop deep understanding. Without sufficient utilization of inquiry in the classroom, science instruction may become full of facts devoid of understanding (AAAS, 1993).

Grounded in constructivist theory and the Science Curriculum Improvement Study learning cycle (Karplus & Thier, 1967), the Five Essential Features of Classroom Inquiry (5E) instructional model (Bybee, 2006) is designed to facilitate in the understanding of complex scientific concepts through the effective use of inquiry. As advocated by the National Research Council (2012), the 5E instructional model facilitates the development and implementation of inquiry-based lessons (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook, and Landes, 2006; Bybee, 2009). Each of the phases of the 5E instructional model integrates student prior knowledge, content, as well as scientific practices. There are five phases of learning that are emphasized in this model, each beginning with the letter "E":

- **Engage:** This stage allows the teacher to gauge students' prior knowledge of the pending scientific concepts. Through the posing of questions, encouraging student questions, and other strategies, the instructor is able to generate student interest and curiosity regarding the upcoming lesson. It is during this phase that students are first posed with the instructional task and investigation purpose.

- **Explore**: During this stage, objects or other phenomena related to the lesson are explored cooperatively. This stage allows students, cooperatively, to begin to formulate questions and organize/analyze data related to the phenomena. The primary role of the instructor is to be a facilitator by providing materials and guiding students' focus and exploration.
- **Explain:** Students begin to formulate explanations regarding the scientific phenomena that that is based on evidence, addresses the initial investigation question, and that build on their existing knowledge while proposing a new understanding.
- **Elaborate:** This stage is also known as "extend" because it provides teachers with the opportunity to challenge students' newly learned concepts and understanding through additional activities. For example, this stage allows students the opportunity to compare their findings and explanations with their peers and instructor. This allows students to critically think about and consider alternative explanations to determine their viability. This stage, along with explain, supports and encourages the open communication between students for the sharing of ideas.
- **Evaluate:** This stage gives students the opportunity to share and justify procedures, evidence, explanations, and alternative explanations. Although listed as the final phase, evaluation can occur throughout the lesson as the instructor determines their students' understanding of critical concepts (Bybee, 2009; Forbes at al., 2013).

This model of instruction advocates the use of active learning strategies that allow students to construct their own knowledge through inquiry. This model allows for the teacher to act as an instructional guide who poses questions that facilitate opportunities for explorations, gathering evidence, and formulating explanations. This approach differs greatly from the traditional approach to instruction where the teacher holds the primary responsibility of simply providing disconnected bits of information to students. Adequate planning and implementation of effective lesson plans are the foundation of quality instruction. Lessons that exhibit the 5E's address both content knowledge and scientific practices that are essential for supporting the construction deep understanding as it relates to science (NRC, 2012).

PROMOTING STUDENT SUCCESS

Teacher Beliefs and Attitudes

Teacher attitudes and beliefs toward science are thought to be critical to the effectiveness of science teachers (Johnston & Ahtee, 2006). This is particularly true for those seeking to implement inquiry-focused science practices in the classroom. Beliefs can be defined as the dispositions to action that determine our course of thought and proceeding actions (Brown & Cooney, 1982). In science education, particularly in utilizing inquiry, beliefs about how individuals learn, pedagogical philosophy, and the resulting implications can have a profound impact on student learning (Haney, Lumpe, & Czerniak, 2003; Savasci & Berlin, 2012). Therefore, teacher beliefs can play a significant role in the development and use of curriculum and materials. How science is learned and how knowledge is gained and measured are typical components of a teachers' pedagogical philosophy. The belief that knowledge is generative rather than transmitted can directly affect the utilization of inquiry in the classroom (Roehrig & Kruse, 2005). Inquiry requires the instructor to connect fragmented pieces of information and organize material in a way that is readily understood by students (Crawford, 2007). Therefore, teachers must spend a substantial amount time teaching and discussing scientific topics with students. However, extensive research has demonstrated that teachers with negative beliefs regarding science tend to have negative attitudes about science (Skamp, 1991; Tosun, 2000; Yates & Goodrum, 1990), rely on more didactic methods on instruction when teaching science (Alonzo, 2002; Windschitl, 2003), and have lower content knowledge (Darling-Hammond, 2006; Heller, Daehler, & Shinohara, 2003).

Historically, content knowledge and pedagogy were thought of as two separate entities. It wasn't until later that Schulman (1987) introduced the notion of combining pedagogy and content knowledge into what is formally known today as Pedagogical Content Knowledge (PCK). PCK skills include the ability to transform content knowledge into lessons that are easily comprehended by students while inquiry-focused science instruction is a process in which students construct their own knowledge through investigation, problem-solving, and building knowledge (Alberta, 2004). In order to successful employ PCK, teachers must have strong content knowledge utilized in tandem with effective instruction. Teachers with stronger content knowledge tend to use a more indirect, less teacher-centered instructional approach. These teachers pose more questions and encourage their students to consider alternate explanations and conduct deeper-level investigations. Teachers who lack content knowledge generally use a more teacher-centered, non-exploratory approach to science instruction. These teachers forgo reflective practices and tend not to encourage students to construct their own knowledge through investigative practices (Alonzo, 2002; Sanders, Borko, Lockard, 2003; Windschitl, 2003). Studies have also shown that teachers who viewed science knowledge as generative rather than concrete tended to use more inquiry-based activities (Cunningham, 1998; Lederman; 1999; Roehrig & Luft, 2004). This attitude and pedagogical preference leads teachers to ask probing questions and encourage alternate explanations. Knowledge and beliefs combined with features of a curriculum and school contexts strongly influence how teachers plan, enact, and adapt curriculum materials (Biggers, Forbes, & Zangori, 2013).

Value Beyond School

Through the use of inquiry, students are more likely to make substantive connections between societal issues and experiences that they have or will face in the future (Newmann, King, & Carmichael, 2009). Learning the thought process, critical thinking, and problem solving skills that will be utilized not only in science careers, but as a critical facet of civic responsibility, is an imperative skill students need to acquire during school years. Leaning to think in a context outside of the classroom in order to effectively learn how adults solve problems is the foundational principle referred to as value beyond school. As explained by DeBoer (2000), understanding information presented through various types of media, critically evaluating and understanding how this information pertains to an individual problem, career or personal situation, and using conclusions in order to become informed citizens should be the primary goal of science education. When skills that have value beyond school are acquired, students learn theories, procedures, and concepts that are applicable to real life situations, regardless of personal relevance (Newmann et al., 2009).

Innovative Instruction

Traditionally, curriculum and instruction were teacher-centered. It was the responsibility of the instructor to present specific facets of information to their students, whose responsibility was to passively accept this information. A paradigm shift advocating the use of more student centered methods that are anchored in constructivist theory, such as active learning (Prince, 2004), cooperative learning (Millis & Cottell, 1998), and modular instruction (Donnelly & Fitzmaurice, 2005), has taken place. Active learning and cooperative learning are instructional techniques that provide students with the opportunity to be active contributors in their quest to construct knowledge. Active learning, by definition, is “anything that involves students in doings things and thinking about what they are doing,” (Bonwell & Eison, 1991, p.2). Cooperative learning is an instructional approach in which small group work is the foundational facet. Students are able to work together, share ideas, and discuss relevant topics in an effort to maximize learning (Millis & Cottell, 1998). Cooperative learning also promotes student engagement and achievement through reduced individual competition among classmates (Prince, 2004). Both of these instructional methods are attempts to create effective and innovative learning environments that encourage students to be engaged in learning, discuss ideas, and explore alternative solutions, all of which require higher-order thinking skills (Newmann & Associates, 1996; Barak, Lipson, & Lerman, 2006).

The creation of an effective learning environment requires instruction to be delivered in a way that is most conducive to the way students learn. According to constructivist learning theory, individuals learn most effectively when allowed to build their own knowledge through exploration and conjuring ideas and alternative explanations. Needless to say, this change has had a substantial impact on curriculum design, spawning the use of modular instruction (Donnelly & Fitzmaurice, 2005). Educational modules are curriculum units in which a topic or concept is studied over a period of time. Modules are designed to be used as individual, standalone units or can be combined in tandem with other units to cover a broad topic or an entire course. This allows for students and teachers to gain deeper knowledge about a specific topic through a sequential learning.

The best designed lessons can fail if the method of instruction is inappropriate and ineffective (Donnelly & Fitzmaurice, 2005). One approach to science education that addresses the need for quality instruction, and focuses on both teacher and student learning is the use of educational modules (Donnelly et al, 2005). Science education modules go beyond a lesson plan. Modules are based on a specific concept and are comprised of building blocks that allow students to learn the concept in a meaningful and sequential method. Effective module implementation promotes deep learning through the inclusion of substantial conversation with the teacher and other students, connecting new ideas to previous knowledge, supporting clear and concise background information regarding the module concept, and supporting the culmination of ideas and explanations through the exploration of materials and resources (Biggs, 1999; Ramsden, 1992; Gibbs, 1992; Schneider, Krajcik, & Marx, 2000). Modularized instruction increases the opportunity of mastery because concepts are presented in a logical and sequential order that allow students to build a basic knowledge base, connect new ideas with previous knowledge, and utilize sustained inquiry (Schneider et al., 2000). However, transitioning into a new teaching paradigm can present some difficulties for teachers.

PREVIOUS RESEARCH

There has been a wide range of studies that examine traditional instruction and inquiry-based instruction. Research studies examining traditional and inquiry-based instruction focus on the implementation of strategies that define each method's foundational theory.

Traditional and Inquiry-Based Instruction

Reforming science instruction to support student learning through the utilization of thinking processes possessed by scientists has been emphasized by various stakeholders (AAAS, 1993; NRC 1996). These thinking processes are supported through the use of inquiry based practices such as posing questions, testing hypothesis, exploration, substantial communication, and collecting and analyzing information (NRC, 2012). Despite the support for the use of inquiry-based instruction, there is wide-ranging support for the use of more traditional methods of instruction to instill basic scientific concepts and procedures. Results of studies comparing traditional instructional styles to inquiry based instruction styles vary widely. Typically, these studies utilize an experimental or quasi-experimental design where two groups of students are compared; one group is taught using inquiry-based approaches while the control group utilizes a traditional approach.

A study conducted by Chang and Mao (1998) compared the impact of traditional based instruction versus inquiry-based instruction in earth science over the course of four weeks. Results of this study indicated that students that were being taught using inquiry-based methods scored significantly higher on achievement tests and displayed greater positive attitudes towards science than students who were taught utilizing the more didactic approach. A longitudinal study examining the long-term effects of a two-week inquiry-based science camp demonstrated that attendees tended to have a stronger interest in science and science related careers than students who were not selected to participate (Gibson & Chase, 2000).

However, there have been some studies that support the utilization of traditional approaches when compared to other forms of innovative instruction (Kirschner, Sweller, & Clark, 2006; Sweller

2009). Mayer (2004) proposed that minimal guidance approaches have been in used and empirically examined since the 1950s. Despite evidence of the ineffectiveness of these approaches, new forms of minimal guidance approaches appeared every decade. Mayer (2004) proposed this pattern of reinvention gave way to the creation of discovery learning, which led to experimental, and eventually inquiry-based leaning. Kirschner et al. (2006) compared the effectiveness of constructivist, problem-based, discovery, experiential, and inquiry-based teaching and found there was no substantial empirical evidence supporting the use of minimal guidance instructional techniques over traditional instruction. Khlar and Nigram (2003) found that students who learned through direct instruction acquired more basic skills and were able to transfer and apply these skills with equivalent efficacy as those taught utilizing the discovery method. However, it is important to note that discovery instruction is not synonymous with disciplined inquiry. Disciplined inquiry allows students to construct their own knowledge through guidance and the utilization of constructivist principles while discovery inquiry is majority student-led (Schwab, 1962; Shulman & Tamir, 1973).

CONCEPTUAL FRAMEWORK

Academic achievement, especially as it relates to science, is on the forefront of America's educational agenda. Further, engaging and motivating students to become interested in science is critical during the middle school years (Reynolds and Wahlberg, 1991; Singh, Granville, Dika, 2002). Achievement and interest in science are critical to address because these factors will often influence future choices in regards to high school curriculum and career choices. There have been numerous attempts to restructure schools in order to enhance and advance the achievement of students. In the past, this focus has centered on English and Math; however, more focus has recently been placed on science and technology. These reform efforts have been based on measuring student performance in regards to achievement test scores. Inadvertently, this led to teachers focusing on "teaching to the test" and concentrating on the reproduction of factual knowledge/content-based knowledge that is typically found on these assessments, which tend to cover a breadth of factual knowledge within a specific domain. However, in order to prepare students for college and careers, the development of skills related to problem solving and constructing meaning that has value beyond school is critical.

Focusing on teaching practices rooted in the utilization of inquiry can have a substantial impact on these factors. Supporting academic achievement and engagement in science are grounded in the notion that quality instruction will allow students to gain intellectual capital that has value beyond school (Scheurman & Newmann, 1998). In order for instruction to have quality, appropriate instructional practices and beliefs regarding science need to be addressed. As a result, federally funded initiatives, such as the Math and Science Partnership, were developed to improve student and teacher attitudes towards science through the use inquiry based modules. Therefore, the purpose of this study was to examine the extent to which inquiry is promoted in classrooms in this project, the factors that influence inquiry use, and the impact of inquiry use.

RESEARCH QUESTIONS

1. To what extent does inquiry use vary in the creation of a module versus a non-module lesson?
2. Do teachers who use modules demonstrate higher levels of inquiry planning have higher achieving students?
3. What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?

CHAPTER III: METHODS

OVERVIEW

This research was conducted as part of a National Science Foundation (NSF) funded Math and Science Partnership (MSP) grant titled the NanoBio Science Partnership. In order to support science performance of students within the Black Belt region of Alabama, the primary goals of this project are to increase science achievement and interest of students in grades 6, 7, and 8 as well as improve the knowledge and performance of teachers through professional development opportunities. To help achieve these goals, teachers are afforded the opportunity to attend local and regional professional development opportunities designed to support the development and use of inquiry-based instructional strategies. In addition, teachers are provided access to inquiry-based nanoscience instructional modules designed to support inquiry-based classroom instruction.

This study utilized rubrics developed specifically to align with the 5E Instructional Model (Bybee, 2009) and the Next Generation Science Standards (NRC, 2013) in order to examine the level of inquiry present in several aspects of the classroom. The Practices of Science Observation Protocol (P-SOP) developed by Forbes, Biggers, and Zangori (2013), measures the extent to which the essential features of inquiry, as advocated the NRC Framework (NRC, 2012), are present during a lesson implementation. Lesson plans and the extent to which they incorporate the 5E's were evaluated using the 5E Lesson Plan Rubric version two (5E ILPv2) developed by Goldston, Dantzler, Day, and Webb (2010). In addition to these rubrics, information regarding teacher qualities such as teaching orientations, and attitudes were measured utilizing project-developed assessments. Student achievement in science was measured utilizing the science test in the Stanford Achievement Test (SAT-10). The SAT-10 is a standardized achievement test that was used by the NanoBio evaluation team to measure gains in science knowledge of students who participated in the project.

Research Questions

1. To what extent does inquiry use vary in the creation of a module versus a non-module lesson?
2. Do teachers who use modules demonstrate higher levels of inquiry planning and have higher achieving students?
3. What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?

CONTEXT OF STUDY

In Alabama, academic achievement in science is dismal. In 2009, National Assessment of Educational Progress (NAEP) reported Alabama as being ranked 48th in science achievement for eight grade (National Center for Education Statistics, 2009). According to the Math and Science Partnership (MSP) grant proposal (Jeelani, Boyd, Hosur, Qazi, & Wallace, 2011) standardized test scores related to science are, on average, over twenty-percentile points lower in the BlackBelt region as compared to the rest of the state (ALSDE, 2012). In addition, there are apparent inequalities among various student subgroups within this region. Students who are Black and students who are economically disadvantaged are performing at a much lower rate than their peers. Although science achievement, as operationalized by SAT-10 scores, has steadily improved for these subgroups between 2006 and 2009, the opposite is true for six out of the nine partner school districts participating in this project (ALSDE, 2012). Through a National Science Foundation (NSF) grant awarded to a coalition of universities in Alabama led by Tuskegee University, an initiative to address the dismal achievement of students in this region was designed to:

1) Examine the performance of K-12 students in science courses and identifying the school districts and the grade levels for the project interventions,

2) Examine teacher quality, quantity, and diversity at target school districts, and

3) Form a partnership consisting of target school districts, doctoral granting institutions, community colleges, and other organizations that are committed to ensuring students within this area have access to, are prepared for, and encourage to pursue challenging and advanced science courses

There are a total of ten higher education institutions, nine school districts primarily in the Black Belt region, and four other supporting partners who provide unique contributions to the MSP Project (Table 2). The ten higher education institutions, comprised of five universities and five community colleges, have distinct strengths related to NanoBio Science research and education. Each of the universities participating in the project has strengths related to research, advanced science degree offerings, extensive outreach programs, and/or exceptional technology and engineering programs. The five participating community colleges have a critical role in the training of current teachers and the recruitment and development of prospective teachers in the field of science education. Each of these colleges also has exceptional associate degree programs related to science and engineering. Of the nine school districts participating in the MSP project, eight are economically and educationally disadvantaged. The students and teachers participating in this intervention project are located within these nine counties. Lastly, the four auxiliary partners will provide additional supports in order to aid in the success of the project. Table 2 lists the partners and their contributions to this project.

In order to foster an interest in science and encourage the election of advanced science courses in high school and beyond, the MSP project has two focus points. One, this project aims to increase student achievement in science through the utilization of inquiry-based modules and two, to focus on teacher development in regards to promoting more positive attitudes towards science and supporting the implementation of inquiry-based instruction in the classroom. Although the science teachers participating in this project have, on average, over 11 years of teaching experience, 95 professional development hours, and are in constant pursuit of additional certifications, district leaders agree that teachers within these districts must learn to utilize instructional strategies that go beyond conventional, didactic approaches to instruction (Jeelani et al., 2011). Through this project, teachers are provided with opportunities to develop skills that foster student engagement through inquiry and how to implement modules and accompanying 3-D simulations that aid in the explication of complex science concepts.

Table 2. NanoBio Partnerships

Partner Type		Partner Name	Contribution
Higher Education	Universities	Tuskegee Auburn University Alabama State University University of Alabama University of Alabama at Birmingham	-Development of modules -Recruitment and development of prospective science teachers
	Community Colleges	Central Alabama Enterprise State Shelton State Wallace State-Hanceville Wallace State-Selma	-Assist in the training of current teachers in partner districts -Recruitment and development of prospective science teachers
School Districts	BlackBelt	Barbour County Bullock County Dallas County Lowndes County Macon County Montgomery County Perry County Selma City	-Module Implementation -Teacher training -Student participants
	Non-Blackbelt	Lee County	
Auxiliary	Supporting Partnerships	Alabama Math, Science, and Technology Initiative (AMSTI) McWane Science Center Materials Research Science and Engineering Centers (MRSECs) Southeastern Consortium for Minorities in Engineering (SECME)	Provide various forms of professional development for teachers participating in the NanoBio Project.

Description of Module Intervention

The partnership provides professional development to 6^{th}, 7^{th}, and 8^{th} grade science teachers in order to shift instruction from conventional teaching strategies to the use of an inquiry-centered approach. University project partners developed nanoscience modules based on the 5E Instructional Model. The Framework for K-12 Science Education (NRC, 2012) defines the essential features of inquiry and scientific practices (outlined in Table 9) that are critical components of science education. Therefore, modules are aligned with current state content standards and are strongly aligned with essential features of inquiry advocated by NRC Framework (NRC, 2012). Modules were developed by project partners in collaboration with science teachers in order to address difficulties with content delivery and student comprehension of course materials and to facilitate student engagement and achievement in science.

Teachers are supplied with science education modules that are designed by researchers, engineers, and pre and in-service teachers. The intent behind this initiative is to raise both student and teacher knowledge and attitudes towards science through the use of inquiry based modules in the classroom. Teachers attend professional developments (2-3) and a conference (South Eastern Consortium for Minorities in Engineering) each year to a) learn about new modules and b) participate in a hands-on demonstration of select modules based on grade level. However, it is important to note that there are several assumptions related to this project:

A. Teachers understand what is meant by inquiry,
B. Teachers know how to implement inquiry in the classroom, and
C. The modules that are given to teachers are, in fact, inquiry based.

RESEARCH DESIGN

This was a mixed methods investigation examining the quality of instructional planning (inquiry-based) that currently exists in target classrooms and the potential effects regarding student outcomes. Based on the 5E model, the module (project developed) lesson plans were constructed with the intent of promoting the use of inquiry in the classroom. However, contrary to the underlying assumptions of the project, there were some discrepancies among teachers who planned to implement inquiry in their lessons and the actual use of inquiry in their classroom. Through examination of module developed lesson plans and teacher developed lesson plans, data were used to investigate the inquiry-supporting strategies in both module and teacher developed lesson plans. This also provided vital information regarding which critical elements are absent from these lessons as they pertain to the NRC Framework and NGSS (NRC, 2012; NRC, 2013). A nested designed was utilized in which three case studies were concurrently conducted. Data from the quantitative portion of the study (an analysis of module and teacher-developed lesson plans using rubrics) was used to examine the differences in the presence of inquiry strategies implemented between the two sources of lesson plans. The qualitative case studies took a more in-depth examination of how these lessons look different when implemented in the classroom and what adaptations were made to both the module and teacher-developed lesson plans during enactment.

Teaching is a complex, multifaceted activity that is not static and requires a broad spectrum of skills and knowledge (Minstrell & van Zee, 2000; Bodzin & Beerer, 2003). Therefore, utilizing a constructivist-based theoretical framework lended necessity to using multiple measures of analysis. This study utilized both quantitative data (achievement scores, beliefs, attitudes, and inquiry use) and qualitative data (observations and interviews) as indicated in Table 3. In order to provide a deeper understanding regarding the quantitative findings of this study, qualitative data from a smaller group of teachers (n=3) was examined in detail. Therefore, the employment of a mixed methods design was complementary as it provided some elaboration and clarification of results from the quantitative and qualitative components of this study (Greene, Caracelli, & Graham, 1989). Thus, quantitative data were utilized to examine factors that influence the promotion of inquiry in NanoBio classrooms. The qualitative case studies provided a deeper examination of teacher enactment and perceptions of inquiry.

PARTICIPANTS

The population studied consisted of teachers participating in the NanoBio project during the 2012-2013 academic year (n=77). The sample included in this study completed all or some of the teacher attitude and knowledge assessments that were administered during the 2012-2013 project year (n=32). Of the 32 teachers included in the sample, 8 (25%) were male and 24 (75%) were female. All teachers who responded taught 6th grade (n=19, 59.4%), 7th grade (n=5, 15.6%), 8th grade (n=2, 6.3%), or a combination of 7th and 8th grade (n=6, 18.8%) science. Also, recruitment letters were sent out to all teachers soliciting authentic lesson plans they felt exhibited high levels of inquiry. Approximately 23 teachers responded to the call for lesson plans, however, only 18 completed all or part the 2012-2013 assessment and were included in this study. In addition, student level outcome data regarding academic achievement (SAT-10) (n=25), personal value for science (n=26), science interest (n=28), and teacher inquiry strategy use (n=28) was aggregated at the teacher level for analysis.

INSTRUMENTATION

The instruments used in this study served three purposes: 1) to examine the presence of inquiry supporting strategies in module and non-module lessons; 2) to determine the relationship of teacher qualities (inquiry orientations and beliefs) in the promotion of inquiry in the classroom; 3) and to determine potential effects 1 and 2 have on student outcomes (Table 3).

Table 3. Data Sources for Analyses

Data Sources		
Teacher Orientations	***Student Outcomes***	***Objective Inquiry Measures***
Inquiry Strategy Use (AIS)	Academic Achievement (SAT-10)	Lesson Plans (5E LP Rubric)
5Es of Inquiry Teaching (5Es)	Personal Value for Science	Observations (P-SOP)*
Perceived Benefit	Science Interest	Interviews*
Perceived Need	Teacher Inquiry Strategy Use (IS)	

*Case study teachers only

Teacher Orientations

As part of the larger study, faculty members in the College of Education at Auburn University were contracted as external evaluators. In order to assess progress towards the goals and objectives set forth by the NanoBio project, members of the evaluation team developed a self-report measure to assess teacher attitudes about the NanoBio project as well as use and orientations towards inquiry methods (see Appendix A). The complete measure, which was administered to NanoBio teachers, consisted of a total of 12 scales. Four of those scales, perceived need, perceived benefit, inquiry strategy use, and 5Es of Inquiry Teaching were used or adapted for this study. Each of the scales consisted of items that were drawn from the database of the Math and Science Partnership – Motivation and Assessment Program (MSP-MAP).

The purpose of MSP- MAP rests in creating and disseminating reliable and valid scales that assess student and teacher factors that impact math and science achievement (Karabenick & Maehr, 2007). MSP-MAP conducts extensive literature reviews and validation studies of MAP developed measures related, but not limited, to beliefs, achievement goals, and self-efficacy about math and science (Schieb & Karabenick, 2011; Wilson, Taylor, Kowalski, & Carlson, 2010; Karabenick & Conley, 2011; Karabenick, Wolley, Friedel, Ammon, Blazevski, Bonney, Groot, Gilbert, Kelly, Kempler, & Musu, 2007; Lauren & Karabenick, 2013). The instrument was reviewed by content and psychometrical experts on the evaluation team and various NanoBio research team members at partnering higher education institutions (see Table 2) in order to examine content validity and alignment with project goals. Detailed descriptions of each scale used for this study along with reliability coefficients are outlined in the following sections.

Perceived Need and Benefit

One goal of the NanoBio project is to "improve the knowledge and performance of in-service teachers through intensive professional development," (Jeelani et al., 2011). In order for this goal to be attained, it is critical that teachers are motivated to participate in the project (attend professional developments and utilize modules). According to Kallestad and Olewus (2003), those who recognize a specific need for innovation and believe the innovation will produce desired benefits, feel more confident in their ability and have requisite skills are more likely to implement a program as intended. Thus, as part of the teacher assessments, teachers were asked to respond to four items, which measured the **perceived need** of the intervention to increase teacher effectiveness and four items that measured teachers' **perceived benefits** of participating in the project (Table 4). Both scales consisted of 5-point Likert-type items ranging from "1-not at all true" to "5-very true" and showed high internal consistency ($\alpha=0.97$)

Inquiry Strategy Use

One of the expected outcomes of the MSP project was to increase the use of inquiry science practices of participants. To examine the current use and potential change in use of inquiry practices, participants responded to statements that described commonly used inquiry strategies such as "applying science situation to life outside of school," (see Table 4). The purpose of this scale was to assess teachers' orientation towards inquiry. Each item was measured using a five point Likert-type scale ranging from "1-never" to "5-all or almost all science lessons." The inquiry strategy use scale consisted of 11 items designed to examine the participants' use of common inquiry instructional strategies and showed high internal consistency (α=0.91).

5Es of Inquiry Teaching

The 5Es of Inquiry Teaching scale consisted of 15 items which examined teachers' orientation towards the use of 5Es which support the use of inquiry-based strategies. This measure adheres to the 5E model for science inquiry methods based on a constructivist model asserting the 5 E's: engage, explore, explain, elaborate and evaluate (Bybee, 2009). Participants responded to each item measuring their use of 5E related teaching methods. Each item was measured using a five point Likert-type scale ranging from "1-not at all true" to "5-very true." There were three items for related to each of the 5E scales (engage, explore, explain, elaborate, and evaluate). This scale also had high internal consistency (α=0.90).

Table 4. Teacher Measures and Sample Questions

Measure	**Sample Question or Instrument**
Perceived Need (4)	I think the NanoBio Science project will help me increase my competence in teaching science.
	I think the NanoBio Science project will help me increase my confidence in using inquiry focused teaching methods.
Perceived Benefits (4)	I think the NanoBio Science project will help me increase my students' competence in science.
	I believe I will take away lasting benefits from the NanoBio Science Project.
5E's of Inquiry Teaching (15)	I use questions to probe students' understandings of a concept and to adapt my instruction.
Use of Inquiry (11)	I choose questions in my class that can have many solutions.
Lesson Plans	5E ILPv2
Observations	P-SOP

Student Outcomes

The primary goal of the MSP project is the increase the science achievement and interest of students in a particular region of Alabama. To assess progress towards this goal, students of teacher participants were administered surveys to assess their attitudes and beliefs towards science. As with the teacher assessment, to establish content and construct validity student survey items were drawn from the MSP-MAP database and were reviewed by evaluation and research team members. The student survey data utilized in this study was collected during the 2012-2013 year and was composed of 13 various scales utilized to assess orientations towards science, beliefs, and perception of instructional strategies utilized by their science teacher.

For this study, the value of science, science interest, and inquiry strategies scales were used as measures of student outcomes as they relate most closely to the present study. The science interest scale was utilized to gauge students' genuine curiosity towards science (5 items), personal value scale sought to determine how students' viewed the importance of science (6 items), and the inquiry strategy scale (same scale used for teachers) seeks to examine student perceptions of teacher inquiry strategy use (11 items). Students responded to items on each of the respective scales using a 5 point Likert-Type scale with "1" representing the weakest agreement and "5" indicating the highest agreement and showed moderate to strong internal consistency (Table 5).

Table 5. Student Outcome Measures

Measure	Sample Item	CA
SAT-10 (40 items)	A decibel is a unit used to measure the loudness of sounds. According to the graph, how much louder is the rock concert than the cell phone ring?	.91
Personal Value (6 items)	Science is useful for solving everyday problems.	.66
Science Interest (5 items)	I think that what we are learning in my science class is interesting.	.76
Inquiry Use (11 items)	In science class we analyze data using charts, tables, or graphs.	.83

In addition, student achievement was measured using the science portion from the Stanford Achievement Test (SAT-10). One of the primary goals of the NanoBio project is to increase science academic achievement through improved teacher knowledge and performance expectantly as a result of professional development. Therefore, the purpose of this assessment was to measure student knowledge gains over the course of each year with the assumption of greater student academic achievement is support through greater teacher orientation towards and use of inquiry-based strategies. Students were administered the 40-item assessment twice per year (Fall and Spring).

Objective Measures of Inquiry and Strategies Supporting Inquiry

5E Model Validity for This Study

Construct validity examines if an instrument measures what it intends to measure. The focus of this study essentially centered on the use of inquiry in the classroom and the potential impact inquiry had on student outcomes. The NRC (1996, 2012), NRC (2013), and AAAS (1993) strongly advocate that learning about and applying scientific inquiry practices should be emphasized in science education. Inquiry-based practices in teaching can facilitate exploratory activities that create opportunities for students to collect data, draw conclusions, and explain results. Incorporating the Five Essential Features of Inquiry (NRC, 2000), provide students with the opportunity to understand and apply such practices that are used by real world scientists. Being able to create an inquiry-based lesson plan is critical to facilitating inquiry in the classroom.

NSES states that inquiry, in terms of instruction, “refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world,” (p.23) and inquiry-based teaching should facilitate “authentic questions generated from student experiences is the central strategy for teaching science.” (p.31) (NRC, 2000). The 5E model provides a framework that supports the planning and use of inquiry in the classroom as described by the NSES. Grounded in constructivist theory, (5E) instructional model is designed to facilitate in the understanding of complex scientific concepts through the 5 phases of learning emphasized in this model (Bybee et al., 2006; Bybee, 2009). This model allows for the teacher to act as an instructional guide who poses questions that facilitate opportunities for exploration, gathering evidence, and formulating explanations that give way to inquiry-based practices. Although the 5E Instructional Model (5Es) and inquiry are not synonymous, the 5E model provides a constructivist based framework for lesson planning and pedagogical practices that strongly support the use of inquiry practices in the classroom (Wilson, Taylor, Kowalski, & Carlson, 2010). The table below displays the alignment of the Five Essential Features of Inquiry (NRC, 2000) with BSCS 5E model's student and teacher roles (Bybee et.al, 2006; Wilson et al., 2010).

Table 6. 5E Model Student and Teacher Roles with the Five Essential Features of Inquiry Alignment

	BSCS 5E Model		The Five Essential Features of Inquiry
	5Es- "What the Teacher Does"	5Es- "What the Student Does"	
Engage	Invites students to raise their own questions, Piques students' curiosity and creates interest, Determine students' current understanding of a concept or idea	Raise questions such as, " what do I already know about this?" "What do I want to know about this?" "How could I find out?"	Learners are engaged by scientifically oriented questions
Explore	Encourages student-to-student interaction, Observes and listens to students as they interact, Asks probing questions to help students make sense of their experiences	Conduct investigations in which they observe describe and record data, Try different ways to solve a problem or answer a question, Compare their ideas to others, "Mess around" with materials and ideas	Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions
Explain	Asks questions that help students express understanding and explanations, Requests justification for students' explanations, Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations	Explain concepts and ideas in their own words, Base their explanations on evidence acquired during previous investigations, Compare their ideas with what scientists know and understand	Learners formulate explanations from evidence to address scientifically oriented questions
Elaborate	Asks questions to help students draw reasonable conclusions from evidence and data Encourages students to use what they have learned to explain a new event or idea Focuses students' attention on conceptual connections between new and former experiences.	Make conceptual connections between new and former experiences, Use what they have learned to explain a new object, event, organism, or idea, Draw reasonable conclusions from evidence and data, Communicate their understanding to others	Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
Evaluate	Observes and records as students demonstrate their understanding of the concepts and performance of skills Provides time for students to compare their ideas with those of others and perhaps revise their thinking	Demonstrate what they understand about the concepts(s) and how well they can implement a skill Asses their own progress by comparing their current understanding with their prior knowledge Ask new questions that take them deeper into a concept or topic area	Learners communicate and justify proposed explanations

In the 2006 America's Lab Report, the NRC conducted a meta-analysis to examine the impact of the 5E model on instruction in the classroom. According to the report, students who were taught using the 5E model showed higher gains in subject matter mastery (Coulson, 2002; Akar 2005), greater sophisticated scientific reasoning (Boddy, 2003), and experienced greater positive changes in attitudes and interest towards science (Tinnin, 2001; Boddy; 2003, Akar, 2005) than students who were taught using other methods of instruction. In addition, Lawson (1995) summarized research on the effectiveness of the learning cycle and found that students whose teachers used this approach experienced greater achievement in science (Renner, Stafford, Coffia, Kellogg, & Weber, 1973), greater understanding of scientific concepts (Barman, Barman, & Miller, 1996; Marek, Cowan, &Cavallo, 1994), and improved attitudes towards science and scientific inquiry (Brown, 1996). These findings coupled with the representation of inquiry demonstrated in each of the 5Es (Table 6) aids in maximizing the construct validity of 5E based instruments used in this study.

Lesson Plans

Study teachers were asked to submit at least two or three lesson plans they felt displayed high levels of inquiry planning. Lesson plans were required to be teacher-developed and teachers were informed not to submit lesson plans that were created by the NanoBio module developers or duplicated from a third party (i.e. online resource). The lesson plans varied in length and format (i.e. full descriptions of activities, materials lists, time allotment). These lesson plans were a critical component of the study as they allowed for an objective view of how inquiry was employed in the classroom.

All modules created by NanoBio module developers included lesson plans to guide implementation. Module developers typically used the 5E framework to guide lesson plan development. Both module and teacher-developed lesson plans were evaluated utilizing the 5E ILPv2 rubric developed by Goldston, Dantzler, and Day (2010).

5E Lesson Plan Rubric

The 5E ILPv2 (5E Lesson Plan rubric) was designed to evaluate inquiry-based lesson plan development using the 5E instructional model. This instrument allows for the assessment of a teachers' ability to write an inquiry based lesson plan based on the 5E model. Although there are other instruments available to observe inquiry based teaching (Bodzin & Beerer, 2003; Forbes et al., 2013) and instruments for assessing knowledge of inquiry practices and the nature of science (Lederman, Wade, & Bell, 1998; Ackerson, Abd-El-Khalick, Lederman, 1999), the 5E Lesson Plan rubric (Goldston, Sundberg, & Dantzler, 2010), is the only rubric of its kind. This rubric is designed to evaluate teacher developed lesson plans according to each critical phase of the 5E model. There are a total of 24 Likert-type items ranging from "0-unacceptable" to "4-Excellent" per item for a total of 84 points. Of the 24 items, 21 are items are directly associated with the 5E model and were utilized in this study. This instrument encompasses 3 items for the elaborate phase, 4 items for each the engage, explore, and evaluation phase, and 6 items for the explain phase, therefore the highest score for each phase ranges from 12 to 24 (Goldston et al., 2010). Each of the scales assessed the lesson plan's alignment and promotion of the 5E model that supports inquiry-based instruction (Table 7). Each lesson plan was scored using a consensus scoring method. Two evaluators read each lesson plan individually then discussed and agreed on a score for each individual item on the rubric for each lesson plan.

Table 7. 5E Lesson Plan Rubric Scales

5 E Model	5E Inquiry Lesson Plan Rubric	α
Engage (4)	Provides opportunities for student discussion/questions (or invites student questions) (Engage item 3)	0.94
Explore (4)	Student-centered approaches (When appropriate, teacher questions evoke learners' ideas and/or generate new questions from students. May involve predicting, hypothesizing, observing measuring, etc.) (explore item 3)	0.93
Explain (6)	Provides a variety of approaches to explain and illustrate the concept or skill such as demonstrations, group discussions, video/print/audio/computer program materials (explain item 5)	0.96
Elaborate (3)	Provides students with the opportunity to apply the newly acquired concepts and skills to new areas and find real life connections (elaborate items 2 and 3)	0.91
Evaluate (4)	Evaluation criteria are clear and appropriate	0.93

5E Lesson Plan Rubric Validity

To establish content validity for the 5E Lesson Plan rubric, an expert panel of five science educators who have implemented the 5E model for at least ten years assessed the instrument (Goldston et al, 2010). The expert panelists evaluated this instrument to determine if the scales aligned with the 5E instructional model and to evaluate the applicability and usability of the scoring criteria by educators. The 5E ILPv2 (referred to as the 5E Lesson Plan rubric in this study) is a revised version of the original 5E ILP (Goldston et al, 2010). The original 5E rubric consisted of 12 items that aligned with 3 factors (explore, engage/explain/elaborate, and evaluate). The original 5E rubric contained items with multiple elements that were separated into single elements resulting the increased number of factors in the 5E ILPv2. Therefore, the construct validity of the 5E ILPv2 was examined through factor analysis to distinguish if the rubric items loaded onto the intended five factors aligned with the 5E model. Results of the factor analysis using maximum likelihood extraction and promax oblique rotation utilizing scores from teacher's lesson plans (n=224) showed 5 separate theoretical constructs and all items loaded on to intended factors and 85.5% of the variability explained (Goldston et al., 2010). There were no substantive changes in content; therefore no further content validity analyses were performed.

<u>Case Study</u>

The case study component utilized individual case reports and cross-case analysis to provide an objective examination of teacher use of inquiry in the classroom as well as provide a deeper understanding of the quantitative results regarding teacher perceptions of inquiry through interviews and classroom observations. Three NanoBio participant teachers were asked to participate as case study subjects. These three teachers were highly active participants in the NanoBIo project as they regularly attended project sponsored professional developments and frequently used modules (2-3 per year during 2012-2013). However, these teachers varied in their use of inquiry strategies as determined by inquiry use scale on the teacher assessment (Table 8). Using teachers with equal motivation to utilize inquiry practices in the classroom (as determined by module use) but who vary in their frequency of inquiry use (as determined by teacher assessments) may give insightful qualitative results as to reasons contributing to the variation of inquiry use in the classroom.

Table 8. Descriptive Data for Case Study Teachers

Teacher	Grade Level	Inquiry Strategy Use	Frequency of Module Use
Alisa	6	3.70	3
Erica	7	2.80	2
Mariah	6	4.70	2

Interviews

Three case study teachers were interviewed utilizing a semi-structured interview protocol between January and February of 2015 (see Appendix A). The purpose of these interviews was to gain a deeper understand regarding project teachers' definition of inquiry, use of inquiry in the classroom, challenges to using inquiry, and perceptions regarding the NanoBio project. The interview protocol consisted of 16 guiding questions and each interview lasted between 35-45 minutes long. Teachers were not provided with the interview protocol in advance. This was purposeful, as a genuine response in order to receive more forthright answers was desired.

Each interview was transcribed in Word and then analyzed through open coding (Strauss & Corbin, 1990). The open codes (list in Table 9) emerged as each interview transcript was read. A total of three iterations were conducted. The purpose of the first iteration was to examine potential themes that may exist in each teacher's response. The second iteration resulted the development of the open code list and the third iteration contributed to the individual and cross case analysis and allowed for common and divergent themes to be identified. After the identification of the most prevalent themes (see Table 8), interview summaries were synthesized to determine how these teachers were similar in their definitions, perceptions, and enactments of inquiry in the classroom.

Table 9. Interview Codes

Theme	**Sample Codes**
Defining inquiry	Scientific method
	Explanation of answers
Inquiry Planning	Materials
	Modifications to plans
Inquiry Enactment	Release Responsibility
	Guidance
NanoBio Modules	Teacher friendly
	Age inappropriate
Building Student Capacity	Research
	Skill development
Challenges	Control
	Student ability

Observations

To objectively examine inquiry use, observation data were gathered through the use of the Practices of Observation (P-SOP) tool. The P-SOP is designed to assess the presence and effectiveness of essential inquiry features in the classroom explicitly based on the NRC Framework (NRC, 2012). The P-SOP is designed to measure students' engagement in the five essential features of inquiry: questioning, giving priority to data or evidence, explanations, alternate explanations, and justification. This instrument is composed of 20 items that translate to four specific indicators for each feature of inquiry. Each indicator is measured using a Likert-type scale from 0-3 with "0" being not present and "3" being the highest form of enactment. The P-SOP provides two scores, one composite score for each of the five features and an aggregate score for across all five critical indicators. Therefore, each feature can yield up to 12 points and the highest total score across all features is 60 points. This instrument demonstrated reasonably strong internal consistency for the aggregate and scale scores (range 0.71-0.98) (Forbes et al., 2013).

P-SOP Validity

To establish construct validity, P-SOP developers performed an extensive literature review involving over one hundred peer reviewed manuscripts which reported the results of empirically based/supported research or theoretical perspectives regarding inquiry-based science instruction. Also, the developers utilized three expert external reviewers in the fields of science education and measurement. These processes defined the specific indicators of inquiry instruction around which the PSOP was developed and aligned. This instrument has been substantially field-tested and compares well to other inquiry based observation tools in the field (Forbes et al., 2013).

VALIDITY AND RELIABILITY

Utility and Social Consequences

According to Messick (1994), when determining the validity of any instrument, the use and consequences of scores must be taken into account. Therefore, ensuring the instruments and their results are only used for the purposes intended are imperative. These rubrics will be used only for the purpose of assessing the quality of instruction by determining the level of inquiry and the presence of the 5E model that is currently utilized in specified classrooms within this study.

The P-SOP provides explicit instructions and how scores form these rubrics should be utilized (Forbes et al., 2013). The researcher used these scores as comparison factors for student achievement, attitudes, and teacher orientations (e.g. use of inquiry strategies). The Framework for K-12 Science Education (NRC, 2012) defines the essential features of inquiry and scientific practices (outlined in Table 10) that are critical components of science education. Delivering quality science instruction requires the effective utilization of inquiry to facilitate the understanding of scientific concepts to support the development of scientifically literate students. As demonstrated by previous research, attitudes and beliefs can have substantive effects on inquiry use in the classroom. Understanding how these constructs are related to inquiry use will be useful in determining where and how professional development efforts and curriculum development training should be best structured. Therefore, using instruments that are empirically and theoretically aligned with these constructs allowed the determination of inquiry use within the classroom.

Although student achievement has been used as an indicator in several other studies utilizing various teacher evaluation tools, P-SOP scores with teacher orientations and beliefs are domains that are not represented extensively in the literature. As demonstrated by the literature, inquiry-based instruction and teacher attitudes have all separately been shown to relate to higher student achievement. Also, the P-SOP framework was developed to be explicitly aligned with the Five Essential Features of Inquiry that are demonstrated by the NRC Framework (2000), therefore rendering this rubric appropriate to be utilized for the purposes set forth by this study. The goal of these professional development initiatives is to improve teacher effectiveness that is typically measured by student achievement (measured through standardized test scores) and teacher qualifications. However, these studies have been typically utilized in various academic subjects (especially social studies), but not extensively in science (Avery, 1999; Lee, Smith, & Croninger, 1999; Newmann, Lopez, & Byrk, 1998). This study will be used within these same domains while adding the dimension of teacher attitudes and orientations within the area of science.

Table 10. Alignment of Scientist Practices, Inquiry Frameworks, and Study Assessments

Practices Used By Scientists	Essential features of Inquiry	The 5 E Instructional Model	NRC Framework	Assessment
Asking questions and defining problems.	Learner engages in a scientifically oriented question	Engagement	**Scientific Practices-**Using behaviors and practices that mirror those of real scientists to investigate worldly phenomena	
Developing and using models. Planning and carrying out investigations.	Learner gives priority to evidence in responding to questions	Exploration	**Cross Cutting Concepts:** Learning and emphasizing specific concepts that have use in all domains of science. This requires instructors to have strong content and pedagogical knowledge in understanding how these specific concepts are present in all domains of science.	Lesson Plans- 5E Rubric
Analyzing and interpreting data. Engaging in argument from evidence.	Learner formulates explanations from evidence	Explanation		Instruction- PSOP Inquiry Strategies
Using mathematics and computational thinking.	Learner connects explanation to scientific knowledge	Elaboration	**Disciplinary Core Concepts:** Emphasizes that it is impossible to teach all students all concepts and ideas about science. This means that there should be a focus on a limited number of concepts by which students gain a deeper level of understanding and will be able to effectively apply this information beyond school. This skill is required to effectively choose information that is reliable and that applies to you or the public.	5E Knowledge
Constructing explanations and designing solutions. Obtaining, evaluating, and communicating information	Learner communicates and justifies explanations	Evaluation		

Reliability

The In order to ensure reliability of rubric implementation, inter-rater agreement was utilized.

P-SOP

Prior to the use of the P-SOP, each rater attended a two-day applied training session facilitated by Sean Forbes (the rubric developer). The goals of the training were to 1) gain an understanding regarding the theoretical background and design of the P-SOP and 2) develop an understanding of each feature represented in the rubric through discussion and applied practice. Each rater utilized the P-SOP to score recorded science lessons to ensure agreement on scores and address any emergent issues. For the observations, two classroom sessions were viewed and scored independently by the researcher and one other colleague. For the P-SOP, interrater reliability established by Cohen's Kappa was calculated. The lesson plans for each of the will be scored collaboratively utilizing the 5E Lesson Plan rubric. The researcher and colleague then met to discuss the scoring criteria for each of the items 5E Lesson Plan rubric in order to establish scoring consistency.

PROCEDURES

The researcher conducted two observations for each case study teacher, one with a teacher-developed lesson plan and one with a project-created module lesson plan. Each observation was evaluated utilizing the P-SOP rubric. The researcher also gathered data regarding student achievement (SAT-10 scores), teacher orientations, and teacher attitudes. These data regarding student outcomes and attitudes are pre-existing and were retrieved from the NanoBio evaluation team's data base. All pre-existing data was aggregated by teacher.

To address research questions 1 and 2, a series of *t*-test analyses were performed to determine if there were statistically significant differences between a) inquiry use in the development of lesson plans created by teachers (teacher-developed) as compared to those created by module developers, b) inquiry use in the development of lesson plans created by teachers who reported using modules as compared to those did not, and c) student outcomes of teachers who reported using modules and those who did not. To reduce the risk of Type I error, an alpha of .01(.05/5- five features of inquiry) was set for "a" and "b," while an alpha of 0.0125 (.05/4- four student outcome variables) was set for "c."

To address research question 3, bivariate correlations were utilized to examine relationships between teacher inquiry strategy use, 5Es inquiry teaching, perceived need, and perceived benefit. Multiple regressions were also conducted to discover the relationships between inquiry strategy use and the other predictors. The backward elimination approach was used to determine the order of which the predictor variables should be entered. R^2 and R^2 change was utilized in order to determine the amount of variance that is accounted for by each of the predictor variables. The standardized Beta weights were used to determine the contribution of each predictor variable in explaining the variance of inquiry strategy use.

Case Study

Descriptive statistics (mean, range, and standard deviation) were reported for the scale and aggregate scores on the P-SOP instrument. Interview data was presented in two categories: cross-case findings (similarities) and individual findings (differences). The findings were used to examine commonalities and differences among all three teachers based on codes and themes that emerge through qualitative analysis (Merriam, 2009; Strauss & Corbin, 1990).

Chapter IV: Results

The purpose of this study was to examine the extent to which inquiry is promoted in NanoBio classrooms. Based on the 5E model, the module lesson plans were constructed with the intent of promoting the use of inquiry in the classroom. However, contrary to the underlying assumptions of the project, there were some discrepancies among teachers who are planning to implement inquiry through their lesson plans and the actual use of inquiry in the classroom. Descriptive statistical analysis, independent samples t-tests, and regression analysis were utilized to examine the following research questions:

1. To what extent does inquiry use vary in the creation of a module versus a non-module lesson?
2. Do teachers who use modules demonstrate higher levels of inquiry planning and have higher achieving students?
3. What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?

DESCRIPTIVE DATA

The population being studied consisted of 77 middle school science teachers in the Black Belt region of Alabama. Participants in the study (n=32) completed all or some of the pre and post assessments that were administered during the 2012-2013 academic year (described in following section). Of the 32 teachers included in the sample, eight (25%) were male and 24 (75%) were female. All teachers who responded taught 6th grade (n=19, 59.4%), 7th grade (n=5, 15.6%), 8th grade (n=2, 6.3%), or a combination of 7th and 8th grade (n=6, 18.8%) science. All participating teachers were certified to teach in Alabama. Typically, to earn teaching certification, one must have earned at least a Baccalaureate degree and be declared proficient in Applied Mathematics, Reading for Information, Writing, and Science through the Praxis and the Alabama Prospective Teacher Testing Program (ALSDE, 2015). In addition, Alabama teachers must complete a teacher preparation program with at least 32 semester hours of credit in their respective academic major (ASLDE, 2015).

MEASURES

In the present study, measures related to lesson planning (**5E Lesson Plan rubric**) were examined in regards to their relation to teacher attitudes (**perceived need, perceived benefits, inquiry strategy use, and utilization of the 5Es)** and student outcomes as defined by academic achievement (**SAT-10**) and student attitudes (**Personal Value for Science, Science Interest, and Inquiry Use).** All measures showed marginal internal consistency as shown in Table 11.

Teacher Measures

According to Kallestad and Olewus (2003), those who recognize a specific need for innovation and believe the innovation will produce desired benefits feel more confident in their ability and have requisite skills are more likely to implement a program as intended. Therefore, teachers were asked to respond to 4 items, which measured the **perceived need** for the intervention to increase teacher effectiveness and 4 items that measured teachers' **perceived benefits** of participating in the project (see Table 11). These items were assessed through the use of self-report measures developed by the evaluation team. All scales consisted of 5-point Likert-type items ranging from "not at all true" to "very true."

Frequency of **inquiry strategy use (AIS)** and **orientation towards strategies that support inquiry use (5E scales)** were measured with a self-report instrument developed by the evaluation team. There were a total of 11 items that measured orientation toward inquiry and 15 items used to measure teacher orientation towards the 5E Instructional Model: engage (three items), explore (three items), explain (three items), elaborate (three items), and evaluate (three items). Each item was measured using a five point Likert type scale ranging from "1-never" to "5-all or almost all" in terms of how frequently strategies or attitudes appear in their science classes.

Table 11. Teacher Measure Descriptives and Reliability

Measure		Sample Item	*M(SD)*	*CA*
Perceived Need (5 items)		I believe the NanoBio Science project will help me increase my competence in teaching science.	4.76 (1.22)	.97
Perceived Benefit (7 Items)		I believe I will take away lasting benefits from the NanoBio Science project.	4.07 (1.16)	.97
Knowledge of 5Es (15 items)			3.98 (0.66)	.90
	Engage	When we start a new instructional unit, it is important to understand students' prior knowledge when planning my instruction.	4.32 (0.65)	.69
	Explore	I encourage my students to follow up an interesting question or problem by performing their own investigation	3.63 (0.97)	.81
	Explain	I use questions to probe students' understandings of a concept and to adapt my instruction.	4.09 (0.84)	.71
	Elaborate	After science concepts are explained, I allow students time to develop their understandings through additional examples and problems.	3.94 (0.82)	.72
	Evaluate	When I assess my students' knowledge, I look for common misconceptions about science concepts.	3.93 (0.67)	.30
Inquiry Strategies (AIS) (11 items)		Discuss alternative explanations for a question or problem	3.47 (0.64)	.91

Lesson Plans

In addition to completing project surveys and assessments, teachers were asked to submit two to three original lesson plans they believed were inquiry based. There were a total of 49 lesson plans submitted by 18 teachers (range=1-6). The 5E Lesson Plan Rubric (5E ILPv2) encompasses 3 items for the elaborate phase, 4 items for each the engage, explore, and evaluation phase, and 6 items for the explain phase (Goldston et al., 2010). Therefore, each scale has the following score ranges: Elaborate= 0-12; Engage, Explore, and Evaluation= 0-16; and Explain= 0-24. Each of the scales assessed the lesson plan's alignment and promotion of the 5E model that supports inquiry-based instruction, see Table 6 (Goldston et al., 2010). Each item was scored using a Likert-type scale that ranged from "0-Unacceptable" to "4-Excellent."

Analysis of the lesson plan data revealed that scale scores for the Engage phase ranged from 1.00-16.00 (*M*=7.90; *SD*=3.65), explore phase ranged from 1.00-16.00 (*M*=6.63; *SD*=3.89), the explore phase ranged from 0.00-22.00 (*M*=6.77, *SD*=5.60), the Elaborate phase ranged from 0.00-11.00 (*M*=2.35, *SD*=2.96), and the Evaluate phased ranged from 0.00-16.00 (*M*=4.42, *SD*=3.89). The maximum score for each scale varied and was dependent on the number of items present. The Engage, Explore, and Explain phases indicated that teachers were about "average" in terms of their use of 5E strategies in lesson planning. However, the Elaborate and Evaluate phases, on average, fair much poorer (*M*=2.35-4.42). According to the scoring criteria set forth by Goldston et al. (2010), teachers were not including key components in either of these phases which center on applying the acquired skills into real-world settings and assuring that the evaluation procedures are clear and appropriate for the activity.

Student Outcomes

Measures for student attitude (**personal value of science, science interest, and inquiry use in the classroom**) along with student achievement (science battery from the **SAT-10**) were used to examine the potential impact of inquiry use in the classroom. All measures were collected as averaged scores at the teacher level. All measures showed good internal consistency as shown in Table 12.

Students were asked to respond to six items, that measured **personal value for science** and five items that measured overall **science interest**. These items were assessed through the use of researcher-developed self-report measures. All scales consisted of 5-point Likert-type items ranging from "1-not at all true" to "5-very true." Also, frequency of **inquiry strategy use** by the teacher was measured with a researcher- developed self-report instrument. As with the items on the teacher survey, these measures adhere to the Five Essential Features of Inquiry (NRC, 2000). There were a total of 11 items that measured the teachers' orientation toward inquiry as perceived by the student. Each item was measured using a five point Likert type scale ranging from "1-never" to "5-all or almost all." To measure academic achievement, the **SAT-10**, a standardized achievement test, was utilized. The science portion of this assessment consists of 40 multiple-choice questions was administered to the students of the participating teachers during the 2012-2013 academic year (*M*=612.48, *SD* 15.78).

Table 12. Student Measure Descriptives and Reliabilities

Measure	N	Sample Item	*M*	*CA*
SAT-10 (40 items)	25	A decibel is a unit used to measure the loudness of sounds. According to the graph, how much louder is the rock concert than the cell phone ring?	612.48 (15.78)	.91
Personal Value (6 items)	26	Science is useful for solving everyday problems.	3.69 (0.34)	.66
Science Interest (5 items)	28	I think that what we are learning in my science class is interesting.	3.14 (0.45)	.76
Inquiry Use (11 items)	28	In science class we analyze data using charts, tables, or graphs.	3.32 (0.46)	.83

RESULTS

<u>*Research Question One:*</u> *"To what extent does inquiry use vary in the creation of a module versus a non-module lesson?"*

Independent sample *t*-tests were utilized when examining the differences in inquiry planning between two groups using the 5E Lesson Plan rubric. Therefore, to address research question one, a series of t-tests established if there is a statistically significant difference in the extent of which strategies that support inquiry were present in module lesson plans compared to the teacher-developed lesson plans. To minimize the risk of Type 1 error inflation associated with multiple t-tests, an alpha level of .01 (.05/5) was used within each grade level.

For sixth grade and seventh grade, the variables examined were the aggregate construct scores for each of the 5E's (engage, explore, explain, elaborate, and evaluate). An assumption of the *t*-test is the variables are normally distributed within each group and the variation of scores is not statistically significantly different resulting in the reduction of a Type I error. With an alpha set to .05, results of the Levene's Test of Equality of Variances indicated that equal variances could be assumed for each variable included in the sample for both sixth and seventh grade.

Sixth Grade

On average, the module lesson plans demonstrated a greater presence of each the 5Es. However, four of the 5Es in this sample (Engage, Explore, Explain, or Elaborate) failed to reach criteria for statistical significance. However, the independent samples t-test indicated there was a significant difference in the Evaluate mean scores between the two groups. The mean Evaluate score for teacher-developed lesson plans was 4.50 (*SD*=4.04) and the module lesson plans mean score was 12.56 (*SD*=4.72). These results suggest that for the sixth grade lesson plans, the teacher-developed and module lesson plans are comparable on four of the phases of the 5E Instructional Model, however, the evaluate phase for the module lesson plans adheres to the model stronger than teacher-developed plans.

Seventh Grade

As shown in Table 13, the t-tests for all 5Es, with exception of elaborate, indicated statistically significant differences between the teacher-developed and module lesson plans. Overall, the 5E Lesson Plan means are greater for the module lesson plans (*M*=4.80-15.60) are higher than teacher-developed lesson plan means (*M*=2.04-13.30). Specifically, as with the sixth grade lesson plans, the Explore and Evaluate mean scores indicated greatest difference, $t(32)=-5.45$ and $t(32)= -5.91$, respectively.

Table 13. *t*-Test Results for Lesson Plans

		Sixth Grade					Seventh Grade				
		N	*M (SD)*	*t*(28)	*P*	Effect Size	N	*M (SD)*	*t*(32)	*P*	Effect Size
Engage	Teacher	24	8.58 (3.65)	-1.65	.109	0.08	24	7.70 (3.44)	-4.24	<.001	0.36
	Module	6	11.67 (5.68)				10	13.64 (2.75)			
Explore	Teacher	24	7.25 (4.09)	-2.11	.044	0.14	24	6.64 (3.68)	-5.45	<.001	0.48
	Module	6	11.33 (4.80)				10	13.30 (2.21)			
Explain	Teacher	24	7.50 (6.15)	-1.24	.225	0.52	24	6.96 (5.12)	-3.92	<.001	0.32
	Module	6	11.67 (7.81)				10	15.60 (5.25)			
Elaborate	Teacher	24	3.00 (3.00)	.504	.618	0.01	24	2.04 (1.17)	-2.45	.020	0.16
	Module	6	2.33 (2.33)				10	4.80 (2.10)			
Evaluate	Teacher	24	4.50 (4.04)	-3.76	.001	0.34	24	4.75 (3.91)	-5.91	<.001	0.52
	Module	6	11.67 (4.72)				10	12.60 (2.45)			

The 5E Lesson Plan rubric was used to examine evidence of inquiry practices when planning instruction. The purpose of this question was to explore the differences, if any, in planning inquiry-based lessons between the module developers and the teachers. As demonstrated by the series of *t*-tests analysis discussed previously, there were some statistically significant differences between the module and teacher-developed lesson plans. Module lesson plans demonstrated greater use of inquiry in planning the evaluate phase ($t(28)=-3.76$, $p=.001$) for sixth grade and the engage ($t(32)=-4.24$, $p<.001$), explore ($t(32)=-5.45$, $p<.001$), explain ($t(32)=-3.92$, $p<.001$), and evaluate ($t(32)=-5.91$, $p<.001$) phases for seventh grade. Therefore, these results suggest that module lesson plans typically incorporate more inquiry practices than those created by teachers.

<u>Research Question Two:</u> *"Do teachers who use modules demonstrate higher levels of inquiry planning have higher achieving students?"*

Although teachers are not producing lesson plans equivalent to project developers, the next research question examined potential differences in use of inquiry practices in teacher-developed lesson plans if a teacher reported using any of the modules. Due to restrictive sample sizes, a series of independent *t*-tests were utilized to a) determine if there was evidence of greater inquiry use in lesson plans created by teachers who used modules and b) if the students of teachers who used modules demonstrated more positive attitudes and greater achievement in science than students of teachers who did not.

First, to examine if teachers who used modules demonstrated greater use of inquiry when planning lessons, a *t*-test analysis was utilized to evaluate the potential differences in lesson plans developed by teachers who reported using a module (n=8) and teachers who did not (n=7). Results of the Levene's Test indicated that equal variances could be assumed at an alpha of 0.05. To reduce the risk of Type 1 error inflation associated with multiple *t*-tests, an alpha level of .01 (.05/5) was used.

To examine if differences in inquiry use when planning exists between teachers who used modules (module user) and teacher who did not use modules (non-module user) existed, the 5E Lesson Plan rubric was used to assess lesson plans from both groups. As illustrated in Table 14, the mean scores across all scales on the 5E Lesson Plan Rubric for module users (*M*=3.46-9.29, *SD*= 3.84-6.50) is higher compared to non-module users (*M*=2.17-6.97, *SD*=2.19-4.31). However, *t*-test results indicate there was no statistically significant difference in inquiry use between the lesson plans created by module and non-module users.

Table 14. *t*-test- Comparing Lesson Plans of Module to Non-Module Users

	Non-Module User (n=7)		Module User (n=8)		*t*- test		
	M	*SD*	*M*	*SD*	*t*(13)	*P*	Effect Size
Engage	6.97	3.16	9.29	4.03	-1.23	.242	0.10
Explore	6.05	2.96	7.75	4.58	-0.84	.419	0.05
Explain	6.05	4.31	8.37	6.50	-0.800	.438	0.05
Elaborate	2.17	2.19	3.46	3.84	-0.783	.448	0.04
Evaluate	3.88	3.41	6.12	5.54	-0.923	.373	0.06

A series of independent samples *t*-tests were conducted to determine if significant differences in outcomes as defined by greater academic achievement (SAT-10) and better attitudes towards science (personal value of science, utility of science and inquiry strategies) between the students of teachers who utilized modules (module user) compared to students of teachers who were classified as non-module users. Table 15 describes the results of the t-test for each outcome tested. All means for students of module users were slightly higher than those of students of non-module users, however these differences were not statistically significant ($p<.0125$) with extremely small effect sizes.

Table 15. *t*-test Student Outcomes

	Non Module Users			Module Users					
	N	*M*	*SD*	*N*	*M*	*SD*	*t*(26)	*P*	Effect Size
SCI	14	3.11	0.43	14	3.15	0.50	-.246	.808	0.002
IS	14	3.35	0.47	14	3.29	0.47	.363	.720	0.005
PV	13	3.68	0.41	13	3.72	0.27	-.292	.773	0.003
SAT-10	14	611.09	17.02	11	614.25	14.67	-.489	.630	0.009

The purpose of this question was to determine: a) if teachers who used modules (module users) displayed greater use of inquiry when planning lessons and b) if students of module users had greater outcomes. To examine differences in inquiry use when lesson planning between module and non-module users, the 5E Lesson Plan rubric was used. *T*-test analysis revealed there were no differences in inquiry use between the two groups when planning inquiry-based lessons. Next, student interest in science (SCI), personal value for science (PV), inquiry strategy use by the teachers (IS), and science achievement (SAT-10) were examined using *t*-test analysis and no statistically significant differences were found. In sum, regardless whether or not a teacher utilized a module, there were no differences in use of inquiry strategies nor were there any differences in student outcomes.

Research Question Three: *"What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?"*

The purpose of this study was to examine the extent to which teachers promote inquiry in the classroom, how this instruction impacts student achievement, and examine the effects of teacher attitudes and beliefs on the use of inquiry-based instruction. As demonstrated by the results of research questions 1 and 2, teachers who utilized modules do not statistically differ from non-users in regards to lesson planning and student outcomes. However, as a follow up question to research question two, research question three examines teachers' 5E use, perceived need, and perceived benefit of project participation in relation to reported inquiry use. The third research question in consisted of both quantitative and qualitative measures. In order to address this question, the following approaches were utilized:

a. Quantitative Component: Examine the relationship between teachers' attitudes (perceived Need, perceived Benefits, 5E score) and Use of Inquiry.

b. Case Study Component (3 teachers):

    i. Identify three teachers that demonstrate varying use of inquiry (one low, one mid, and one high level)

    ii. Examine teachers enactment of inquiry based lesson plans through observations

    iii. Interview each teacher regarding their perceptions, use, and ideas regarding inquiry

Quantitative Results

To address research question 3, correlational and multiple regression analyses were conducted to examine the relationship between inquiry strategy use and perceived need, perceived benefit, and 5E score. Multiple regression analysis was appropriate due to the continuous independent variable and dependent variables. A backward elimination approach was used to examine the overall regression model and one restricted to predictors that were statistically significant.

Bivariate correlations were used to explore the relationships between the teachers' self-reported use of inquiry strategies (AIS), perceived need for the project, perceived benefit for the project, and use of the 5Es (Table 16). The strongest relationships were between inquiry strategy use (AIS) and perceived benefit (*r*=.439, *p*<.01) and 5Es of Inquiry Teaching (5E total) (*r*=.727, *p*<.01). The weakest relationships were between perceived need and inquiry strategy use (*r*=.057) and the 5E total (*r*=.163). The analysis indicated the strongest relationship exists between the teacher reported use of inquiry strategies and their knowledge of the 5Es. To determine which of the 5Es had the greatest impact in predicting the use of inquiry strategies, a multiple regression analysis using the backward method was utilized. Bivariate correlations between all 5Es and use of inquiry correlated strongly (*p*= .000-.012).

Table 16: Pearson Correlations for Measures of AIS, PN, PB, and 5E n=29

	AIS	Perceived Need	Perceived Benefit	5E Total
AIS	1			
Perceived Need	.057	1		
Perceived Benefit	.439**	.456**	1	
5E Total	.727**	.163	.654**	1

**p*<0.05; ***p*<0.01

The full regression model with all three predictor variables, Perceived Need, Perceived Benefit, and 5E score resulted in a large effect size (R^2=.543) and was statistically significant (*F*(3,24)=9.495, *p*<.001). However, the 5E score was the only variable that was statistically significant (Beta= .783, *p*<.001) Although there were strong correlational relationships between inquiry strategy use and teacher perception of project benefit, small beta weights and semipartial correlation coefficients for perceived need and perceived benefit prevented these variables from being retained in the final regression model. The final model was restricted to just one predictor, knowledge of the 5Es, and resulted in a large effect size (R^2=.528) and was statistically significant (*F*(2,24)=30.06, *p*<.001). In comparison to the full model, the restricted model was not statistically different (R^2 change=-.007, Sig *F*-Change=.844), so the restricted model is preferred.

Table 17. Multiple Regression Model for Predicting Inquiry Strategy Use

	Full Model		Restricted Model	
Variable	Beta	r_{sp}	Beta	r_{sp}
5E Score	.783**	.649	.732**	.732
P.N.	-.045	-.058	-	
P.B.	-.066	-.065	-	

a.Predictors: Constant, Need, Benefit, 5E, R^2=.543, F=9.50**
b.Predictors: Constant, 5E, R^2=.536, F=30.06**,ΔR^2=-.007, ΔF=.171, Sig ΔF=.844
c. N=29, *p<0.05; **p<0.01

The 5E are composed of five distinct constructs (engage, explore, explain, elaborate, and evaluate). The total 5E score demonstrated to be a significant predictor of inquiry use in the classroom. As illustrated in research question one, different constructs within the 5E model had variable contributions to the overall presence of inquiry in regards to lesson plans. Therefore, to examine the relationship of these constructs with teacher reported use of inquiry in the classroom, a regression analysis was conducted.

A Pearson product-moment correlation was conducted to examine the relationship of all 5E constructs with teacher inquiry use (Table 18). All five constructs showed strong statistically significant relationships with inquiry use.

Table 18: Intercorrelation Table for 5Es

	Inquiry Strategies	Engage	Explore	Explain	Elaborate	Evaluate
Inquiry Strategies	1					
Engage	.391*	1				
Explore	.669**	.605**	1			
Explain	.664**	.710**	.710**	1		
Elaborate	.770**	.594**	.726**	.819**	1	
Evaluate	.640**	.535**	.450**	.695**	.686**	1

*p<0.05; **p<0.01

A series of multiple regression analyses utilizing the backward method were conducted in order to examine the relationships between the individual 5Es and teacher reported use of inquiry (Table 19). The full model with all five predictors produced R^2=.684, F(1,27)=11.71, p<.001, with Explore (Beta=

.368, p<.05), Elaborate (Beta= .474, p<.05), and Evaluate (Beta= .317, p<.05) contributing significantly to the model. Therefore, a restricted model with Explore, Elaborate, and Evaluate produced (R^2=.647, F(1,27)=17.76, p<.001). Although the beta weights for all three of these predictors dropped slightly and the R^2 (F-Change= 1.158, p=.224) was not significant in the restricted model, this supports the implied differences found in research questions one and two that the explore and, especially the Elaborate and Evaluate phases are indicators of the differences in teachers who readily understand and utilize inquiry in their classroom.

Table 19. Multiple Regression Model for Predicting 5E Relationship to Inquiry Strategy Use

	Full Model		**Restricted Model**	
Variable	**Beta**	r_{sp}	**Beta**	r_{sp}
Engage	-.245	-.168	-	-
Explore	.368*	.230	.256	.175
Explain	-.053	-.025	-	-
Elaborate	.474*	.238	.423*	.236
Evaluate	.317*	.212	.234	.170

a.Predictors: All 5Es, R^2=.684, F=11.71**
b.Predictors: Explore, Elaborate, Evaluate, R^2=.647, F=17.76**,ΔR^2=-.037, ΔF=1.158, Sig ΔF=.224
c. N=29, *p<0.05; **p<0.01

The quantitative component of research question three sought to identify relationships between teacher attributes (perceived need, perceived benefit, and 5Es of Inquiry Teaching) and the influence of these variances on the use of inquiry in the classroom. Correlational and multiple regression analyses were utilized to examine the effects of these variables on teacher orientations towards inquiry strategy use. Correlational data indicated inquiry strategy use had the strongest relationships with 5Es of Inquiry score (r=.727, p<.01) and perceived benefit (r=.439, p<.01). The perceived need scale was not included in the regression analysis because of its weak relationship with the other variables. Although perceived benefit did have a significant relationship with inquiry strategy use and the 5Es of Inquiry Teaching, the results of both regression analyses indicated that the best predictor for inquiry strategy use were the 5Es of Inquiry Teaching. Specifically, explore, elaborate, and evaluate best predicted use of inquiry strategies.

Supporting Case Studies

This section presents the findings from the qualitative component of the third research question, "What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?" In order to better understand potential differences in the perceptions and implementing regarding inquiry amongst project teachers, three participants were chosen as case studies. All three teachers responded very positively on the attitudes survey indicating the belief that there was a great need for the intervention and they saw how it could benefit the students, however, their self-reported use of inquiry strategies (AIS) varied. The inquiry strategy use measure consisted of 11 5-point Likert type items. One study case teacher indicated low use (M=2.8), one indicated mid-level use (M=3.7), and the last indicated high use (M=4.7). The three case study teachers were observed implementing a lesson (module or teacher-developed) and participated in a semiformal interview regarding their perceptions and use of inquiry.

The results are divided into three sections a) P-SOP findings; b) cross case findings; and c) individual case reports. First, data from the class observations will be presented. A total of eight classes were observed (teachers=7, project module developers=1). Two team members observed three of those classes. An interrater reliability statistic utilizing the Kappa statistic was performed to determine consistency among raters (Kappa=0.68, (p<.001).

Observations-PSOP

Each scale (n=5) of the P-SOP has four Likert type items ranging from 0 to 3. Each scale has a specific set of anchors for each item, but generally range from "0- no evidence" to "3-strong evidence". Each scale has a maximum score of 12 and the instrument has a maximum composite score of 60. The data revealed that teachers tend to score moderately high in "engaging students in scientifically oriented questions," and "engaging students in giving priority to evidence in responding to questions," phase, *M*=9 and 8.33, respectively, with low variability. During the "engage in scientifically oriented question" phase, question(s) that are answerable through inquiry, contextualized and feasible are used to engage students. The "giving priority to evidence" students' work with data (collection, verification of accuracy, transformation) related to the phenomena. However, scores decline drastically in the "evaluating explanations in light of alternate explanations," and "communicating and justifying explanations" phases (see Table 20). It is during these phases that teachers ask open-end questions, and allow students to make claims and collect data in order to evaluate and justify said claims in light of alternative explanations.

Table 20. Aggregate and Composite P-SOP Scores (n=3)

Elements of Inquiry Measured by the P-SOP											
1		*2*		*3*		*4*		*5*		*Composite*	
M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
9.25	*1*	*8.25*	*0.50*	*5.00*	*2.16*	*1*	*0.00*	*0.33*	*.41*	*24.17*	*2.56*
Range= 8-10		*Range= 8-9*		*Range= 2-7*		*Range= 1*		*Range= 0-1*		*Range= 20-26*	

1 Engaging students in scientifically oriented questions
2 Engaging students in giving priority to evidence
3 Engaging students in formulating explanations from evidence to address scientifically oriented questions
4 Engaging students in evaluating their explanations in light of alternative explanations
5 Engaging students in communicating and justifying their explanations

Overall, when implementing inquiry-based lessons, case study teachers (n=3) showed little or no evidence of engaging students in evaluating explanations or communicating and justifying those explanations as measured by the P-SOP. During these phases, students are comparing results and findings in light of alternative conceptions and perhaps gaining new knowledge about the topic being investigated. Inquiry instruction should facilitate, "authentic questions generated from student experiences is the central strategy for teaching science." (p.31) (NRC, 2000). By not engaging students in these aspects of inquiry, teachers are not fully developing and instilling the scientific practices associated with inquiry. These results support the indication that teachers believe they are using inquiry, but are not incorporating important aspects of inquiry.

<u>Qualitative Findings</u>

The results are presented in two categories, cross-case findings (similarities) and individual findings (differences). First, the cross case findings will be discussed to emphasize the commonalities among all three teachers. Next, the individual case reports will be presented in order to examine how these teachers view inquiry differently from a) each other and b) the framework of what inquiry looks like as set forth by the Five Essential Features of Inquiry (NRC, 2000). Table 21 provides an overview of the case study teachers' quantitative data. Perceived need (PN), perceived benefit (PB), utilization of the 5Es (5E), and inquiry use (IS) were self-report 5-point Likert type items used to measure teacher attitudes while the observation tool (P-SOP) and the 5E Lesson Plan rubric were used as a more subjective measure of inquiry use. Each case study teacher used at least two modules during the 2013-2013 academic year.

Table 21. Scores Across Measures for Case Study Teachers

Teacher	PN	PB	5Es	IS	P-SOP	Freq. Of Module Use	5E Lesson Plan Rubric
Alisa	5.00	5.00	4.33	3.70	26	3	*M*=63.00; r=54.00-75.00 n=5
Erica	5.00	4.57	4.07	2.80	24.5	2	*M*=53.67; r=38.00-63.00 n=3
Mariah	3.00	5.00	5.00	4.70	22	2	M=43.50, r=30.50-54.75 n=3

Cross Case Findings

Across the three case studies, there were three themes that emerged from the interview data: a) challenges related to student readiness, b) building student capacity to think critically, and c) the belief that the NanoBio Modules were, as a whole, insufficient to address the needs of their students.

Ideas about Inquiry

As a whole, the case study teachers defined inquiry as the ability to support conclusions and inquiries with evidence through explanation. For example, when asked to described what inquiry looked like in her classroom, Alisa stated,

> I would ask the question, 'what do you think would happen if we did this?' Or what do you think causes something. And give them a chance to think about, write down what they think would happen. Um, then they have to explain why they think such and such would happen. Why they chose a over b. And I always try to tell them that there is no right or wrong answer, as long as you are able to explain what you think is going to happen and its reasonable."

Mariah had a similar, but narrower view. She described inquiry as,

> My questions don't be a one-sentence answer. They really must… they have to think about it. And go into detail about well first they give the context; they have to pick out the context clues about what the question is about and what I am asking, in science, what I am asking them to do. And then they have to go back and solve the problem and piggyback on what they know and what they learned and tie all of that together.

These teachers believed in the practice of asking "good questions." According to the case study teachers, in order for students to ask questions of sustenance, they must possess the ability to think critically. All three teachers cited the practice of not giving students the answers outright as a tactic commonly employed in their classrooms. Erica explained how she encourages her students to think beyond surface level by creating a culture of questioning her in classroom. She stated,

> They get so frustrated because they are going from elementary to middle school and I don't give them anything. I get them question for question. So, one strategy would be not giving into an elementary mindset because we want to take them to the next level.

Also, all of the case study teachers were confident in their students being aware that the teacher does not always know the answer to their questions. The teachers explained how they will challenge their students to go home, research the topic, and during the next class meeting a discussion will be held regarding their findings. For example, Mariah explained the type of response she will give a student if they ask a question to which she does not know the answer,

> I say,'ohhh that's a good point! Let me go home and find out. Or how about you go home and find out and we can talk about it tomorrow or the next time we meet and we can talk about the information that we found and see if we find the same thing.' So it gets them to look. And besides me looking it gives them a chance to look and their classmates [as well].

All three teachers identified conducting question-driven classes as a critical aspect of inquiry. The foundation component of inquiry rests in the ability to ask and answer scientifically based questions through data analysis, not reading information. Erica explained that it is important to start off the class period, on inquiry days, with a question,

> I am learning that even more this year, is having that major question, even when they walk in. You know this is not a going to be a fill out the worksheet type of class. It is going to be the 'what is the question today and how are we gonna solve it.'

In tandem with the ability to formulate questions, the ability to explain conclusions related to said questions is equally as important. In the 5E model, the explain and elaborate phases related to students explaining their inferences, working collaboratively with their classmates to compare explanations, and elaborate further proceeding those collaborations. Alisa described how this may look in her classroom,

> Um, make sure they are able to explain their reasoning…I tell them if you get the right answer but you don't really understand how you got the right answer then you're not totally correct, but if you have the wrong answer but you are able to explain it then you are not totally wrong. You know, they just have to be able to explain why.

Alisa, the highest self-reported inquiry utilizer, explained how being able to justify your conclusions and inferences, even if it is not aligned with other explanations, is critical.

Although Alisa shows sufficient knowledge and places great value on the importance on asking questions and explaining answers, she holds a somewhat negative view of critical aspects of inquiry such as data analysis. When asked to describe some drawbacks of using inquiry she states,

> [My students] just only want to do the hands on types of activities. Then they are reluctant to do the reading type. When you have to collect your data and analyze your data, they are more reluctant to do that part. They only want to do the other part, the 'fun' part is what they call it.

It is evident that Alisa views data analysis as something that is a part of inquiry, but views it as something her students do not like to do. Alisa claimed that her students are typically not engaged or interested in data analysis which led to her negative view. Her negative view of this critical element may contribute to her focusing on it less during lessons she views as inquiry-based.

Challenges Related to Teaching Inquiry

The most prevalent commonality among case study teachers were challenges related to student readiness. There were two challenges that were discussed extensively. One challenge was related to the students not being at or relatively close to grade level when entering the school year. The students participating in this project are from a region of the state where overall academic achievement is dismal (NAEP, 2009). According to the ALSDE (2012), students participating in this project are, on average, twenty percentile points lower in science achievement as measure by standardized tests than their peers from other parts of the state. Coupled with the extremely rural location of a majority of participating schools, this presents a pronounced challenge for teachers in these areas.

Erica expresses how her students initially have difficulty engaging in fundamental practices of inquiry such as formulating questions and independent thinking. She explains,

> In my classroom I am building background knowledge as I build social skills as I am building [other skills]. You're building all these skills that children come without. Their reading, their writing, their everything. The drawback is to be so focused on the higher level thinking that we don't have the base for higher-level thinking. They don't have the working knowledge for science. They get it in sixth grade, but they don't get it those formative years where you're building in the reading and math.

Erica's explains the difficulty of accounting for inadequate student preparation in the formative years of her students. Inquiry is based on formulating independent explanations of phenomena as opposed to only conducting hands-on activities. Not having sufficient background knowledge and skills creates barriers for thinking on a cognitive level that is critical for inquiry-based instruction.

This challenges leads into exploring difficulties related to the students' ability to think on a higher cognitive level. According to the case study teachers, being able to explain and justify answers is not only an important skill they focus on developing, but also a critical component of inquiry. As stated by Alisa, students need to be able to "think on their own without waiting for the teacher." All three case teachers share the belief that inquiry assists in helping students think outside of the box and develop the skill of independent thinking and problem solving. As Mariah explains,

> They have to solve the problem and piggyback on what they know and what they learned and tie all of that together… they have to know it, so if I call on them, they have to be able to explain it, and once they are able to explain it then I know that they have it.

Module Alignment

A third common theme throughout the case study teachers' interviews centered on not believing the NanoBio modules, as a whole, were sufficient in addressing the needs of their students. Modules were developed by project partners in collaboration with science teachers in order to address the NanoBio project goal increasing teacher effectiveness related to content delivery and student comprehension of course materials and to facilitate student engagement and achievement in science (Jeelani et al, 2011). The modules were designed to align with state standard and facilitate the use of inquiry practices in the classroom (Appendix B). Although the teachers believed the modules supported the use of inquiry in the classroom, they insisted that some of the modules were not developed at a cognitive level appropriate for the desired population. For example, Alisa, who used 3 modules (Sports Drinks and Nanotechnology, Modeling Mitosis, and Barn Owl Pellet-see Appendix B for descriptions), stated,

> The ones that I have used, I think they support [inquiry], but, I know one in particular, to me, they were written at a higher level than my kids were ready for. Like, I said with you, the Sports Drink, I sort of reworded some of the questions here and there and kind of broke it down so that my students could understand it better.

In alignment with the view set forth by Alisa, Erica, who used 2 modules (Barn Owl Pellets and Cell of Ozland), stated that the modules are valuable in the respect of adhering to curriculum standards, however the modules were missing critical steps and clarifications in regards to the topic background. The modules tend to cover higher-level concepts and are "difficult to follow." Erica explained that some of the module lesson plans do not provide enough information, especially considering the topics and concepts that are introduced. She expressed that the modules either provide a) a base or foundation for the standard that will be covered or b) they provide an auxiliary piece that allows reinforcement of what was taught. However, in terms of the lesson plans that accompany the modules, Erica stated,

> Some of the lesson plans that I have found in the modules aren't teacher friendly. But I do make it teacher friendly [i.e. using simplified language that students will understand or only focusing on concepts that students need to know according to state standards]! I do make it teacher friendly for me! I think they lack steps especially with inquiry based. I've looked at several lesson plans that are not completely all the way clear. We 've been in the workshops where you can

> help write, but some of it is higher level, like on the university level and I am teaching a 12 year old whose never had science. So sometimes it's just a little too high for seventh [grade].

Mariah, who used 2 modules (Sports Drinks and Nanotechnology and Storm Chasers), also expressed that they modules kept the students engaged, however it was "missing some pieces." For example, Mariah explained that although the lesson plan for the module was written in a format that technically aligned with the 5Es, the curriculum materials and teacher instructional guides were not easily understood. Mariah stated, "[The lesson plan] didn't fully explain. Even though I was kind of confused, I just came up with my own made up stuff to it."

Although Alisa and Erica felt the modules she utilized were too complicated to use as is with their population, Mariah held the opposite view by stating,

> [The module] really didn't have them thinking as sixth graders. I had to keep them engaged because the activity was nothing but like 20 minutes…. I think it would benefit like a second or third grader, it wasn't a sixth grade activity.

In sum, the case study teachers agreed that the modules were inquiry based and relatively engaging for their students. However, they believed that some the modules were missing critical components nor were the modules written at a level that was appropriate for their students. It is important to note that modules referred to by the case study teachers were, for the most part, developed by individuals who teach science at the collegiate level and may have little, if any, experience in a middle school science classroom. This could account for the disconnect teachers are experiencing between their needs and the support and information provided by the module lesson plans.

Individual Case Reports

Each of the three teachers were chosen for the qualitative component due to their varying ideas and enactment regarding inquiry. Overall, each teacher displayed a high perceived benefit and perceived need of the project. However, each teacher's enactment of inquiry based lessons (module and authentic), definition of inquiry, and inquiry planning varied.

During the semiformal interview, each teacher utilized a 5-point scale to rank essential elements of inquiry as related to their importance in lesson planning (1-Most Important to 5- Least Important). As illustrated by Table 22, all three teachers varied in ranking these elements of inquiry. Although all the case study teachers explained how being able to justify explanations was a critical component of their teaching style in regards to inquiry, all three teachers ranked "justifying explanations," as moderately important (rank= 2-3). Erica and Mariah show similar trends when ranking the categories of "asking scientifically based questions," (rank= 1-2) and "formulating explanations based on data" (rank=4-5). Alisa and Mariah showed similar rankings of "compare explanations" (rank of 5) while Erica ranked this same category as moderately high (rank of 2).

Table 22: Teacher Ranking of Essential Inquiry Elements

	Alisa	Erica	Mariah
Ask scientifically based questions	3	1	2
Collect and use data to answer questions	4	4	1
Formulate explanations based on their data	1	5	4
Compare their explanations	5	2	5
Justify their explanations	2	3	3

Although these teachers vary in their rankings of essential inquiry elements, the demonstration of these elements as indicated by the P-SOP results show that all three teachers tend to orient towards the "engaging students in scientifically oriented questions" and "giving priority to evidence" phases of inquiry. For example, Alisa ranked "formulating explanations based on data" as the number 1 essential element of inquiry, however, when enacting an inquiry based lesson, this feature received the third lowest score as measured by the P-SOP. "Engaging students in formulating explanations from evidence…" was ranked 4th (out of 5) by Mariah and ranked 5th by Erica. Erica and Mariah ranked "asking scientifically based questions" and "collecting and using data" as the most essential elements of an inquiry based lesson, respectively. These rankings are aligned with their enactment of inquiry based lessons in their classrooms as the “engaging students in scientifically oriented questions” and “giving priority to evidence in responding to questions” were scored highest among all three teachers by the P-SOP observation tool.

As highlighted in the previous section and supported in the rankings of essential inquiry elements, these three case study teachers show some similarities regarding their perceptions of inquiry. The following section will expound on the differences in each of these teachers’ perceptions and how these differences impact how inquiry is taught in each of their classrooms.

Alisa

Definition of Inquiry

When defining inquiry, there were three aspects Alisa focused on a) following the scientific method, b) applying knowledge in differentiated settings, and c) varying instructional techniques to enhance comprehension. When teaching inquiry, Alisa expresses the idea of following the scientific method was an indicator of doing science or being engaged in inquiry. According to Alisa, it is important for students to ask questions, construct a hypothesis, and ensure that it is written “in a certain format.” Also, when “doing science,” Alisa stated that her classes are driven by hands-on activities and visual supports such as videos related to the topic of investigation. Supporting the facilitation of learning and applying material and concepts learned in class is of great importance. Alisa states, “To me that is what inquiry is, asking them what they think about a concept or what they think is going to happen in a certain situation. Letting them think about it and discuss why they feel a certain way.” Ensuring that students are learning the material in more the one context to avoid purely situated learning and being able to apply knowledge in multiple contexts and in real life are the driving forces behind this teachers’ definition of inquiry. It is evident that Alisa understands and emphasizes scientific methods such as making educated guesses, utilizing manipulatives, and following formulated procedures are important wen engaging in science teaching. However, asking questions and answering those questions through data analysis is not explained or mentioned in her definition that implies that she does not have a complete understanding of inquiry.

Inquiry Planning and Enactment

When planning inquiry, Alisa explains how it is critical that students have sufficient time to explore, therefore her focus when planning an inquiry lesson is ensuring the proper working order of the equipment. When planning an inquiry based lesson, Alisa explained how the focus is to ensure all of the materials and equipment are in working order so “the focus will be on the activity, not something else.”

When looking at making changes to lesson plans, the changes that Alisa enacted were small, only changing the materials or instructions slightly to ensure a smoother implementation during the other classes. Alisa states, “it may be something I didn’t originally think of. And for the next class I will change it. It may be something like putting an extra paper towel, you know…. Most of the time it’s small.” However, Alisa clarifies that questioning ultimately drives inquiry, in her classroom. She facilitates thinking by encouraging her students to think about the outcome of their experiments when manipulating variables. Hypothesizing, testing said hypotheses, and explaining observations and outcomes are the driving forces when enacting inquiry in her classroom.

<u>Mariah</u>

Definition of Inquiry

Mariah specifically defined inquiry in terms of questioning and explanations. Specifically, Alisa insists that inquiry in her classroom consists of students being able to answer questions fully with thought out explanations. Alisa describes how this looks in her classroom by stating, “I start off with what they already know and what I want them to get from it. It is the way that I have them solve. It is the problem we have to get to today. And I try to do a think critically question that has multiple parts to answer.” Mariah’s questioning technique is more teacher-focused when compared to the other case study teachers. Mariah is focused intensely on how students answer the questions. According to Mariah, students have to explain their answers fully, to Mariah, this is defined as answering in multiple, complete sentences.

Inquiry Enactment

According to Mariah, inquiry is about being able to explain a thought completely and thoroughly with complete sentences with little focus on inquiry strategies such as data analysis. Also, Mariah emphasizes the significance of keeping students engaged. Mariah offers rewards such as bonus points for the "correct" answer or coming back to class with research on an unanswered question from class. She also uses jokes and other types of "entertainment" engagement strategies to keep the attention of her students. For example she explains, "you have to get them engaged, you have to do something to get their attention before and then during the lesson you have to have something. With the kids I teach, I either have to tell them a joke I found about the atmosphere or something to get them interested in it." However, similar to Alisa, when looking at making changes to lesson plans, the changes that these two teachers enacted were, in some respects, superficial. Only changing the materials or instructions slightly to ensure a smoother implementation during the other classes.

Inquiry Planning

Mariah depends heavily on tangible or prescribed materials when focusing on inquiry. Mariah utilizes tools such as subject guides and journals. She also describes that Response to Intervention (RTI) strategies such as utilizing scientifically based classroom instruction materials and differentiated teaching are staple tools when using inquiry. Mariah explicitly stated that she uses the 5Es (engage, explain, explain, elaborate, and evaluate) when planning out her lessons. However, when asked, "How do you use the 5Es when planning," she explained how her classes are on a block schedule (90 minute class intervals) three days a week. Therefore, she focused on how the time blocks within her 90-minute are broken up. The first fifteen minutes is whole group and each time the timer sounds, her students know that it is time to move on to the next activity/station before concluding with regrouping and reviewing their anticipation guides. “I think [inquiry] is very effective in my classroom… And when they do the labs and all of that, they go through the 5Es, they pretty much get it… I had to keep drilling and practicing with them…So I have to keep it, with those two classes, a routine where I’m doing the same things over and over. Once you do the same thing, then they’ll get it, but you have to have a routine.” Through her description of inquiry utilization, Mariah uses key words such as “questioning,” “5Es,” and “differentiated learning,” however, when asked to describe her practices in details, her view of inquiry planning and implementation seems to be regimented and teacher directed.

<u>*Erica*</u>

Definition of Inquiry and Enactment

Erica defined inquiry as exploratory. She believed that, when doing science or inquiry, there needs to be a “big question.” Erica explicitly stated, “ my children come to me not knowing how to think for themselves…[inquiry] pushes the kid out of their comfort zone and my kids come from very small comfort zones!” This quote discloses that Erica believes her students initially struggle with inquiry because they were not accustomed to student-directed practices. Her students were focused on getting the “right answer” and not fully understanding the concept being examined. She stated, “inquiry is digging deeper for the kids [or else] they are not going to grow.” Therefore, Erica indicated that her focus is not ‘giving in to the elementary mindset’ by requiring her students to work collaboratively, ask questions, and discusses issues or findings by ‘baiting and hooking into their curiosity’ and that will lead into discovery, exploration, and ultimately a higher retention of knowledge.

Inquiry Planning

When planning a lesson that is inquiry-based, Erica explained that her lessons center on a ‘big question’ that has a goal or specific focus.

> I constantly [change my lesson plan]. I will think of something and I will be like, 'ohhh let me try this.' I make an outline of what my lesson plans will be for the week but I stay with the basic plan, but I am always accommodating…I constantly change. I will be thinking of something at home and I will say, I'm going to go do that tomorrow. It's really kid oriented.

For example, Erica explained that her classes were going through a unit on bones. The planned activity for one session consisted of students working in small groups to complete a Venn diagram regarding the similarities between human bones and the bones of a frog. However, the students began asking questions regarding the shape of the bones, which eventually led to a lengthy discussion regarding why teeth do not burn even though they are considered a bone. However, she understands that all of her students will have different levels of cognitive ability and motivation, therefore, although her priority is ensuring her students understand concepts through exploration, maintaining an ideal pace is also critical. She acknowledged that inquiry based activities and lessons take more time to implement and teachers are working within specific time constraints set indirectly through curriculum standards and standardized testing schedules.

Summary

The findings from the qualitative component of this question examined and expounded how these three case study teachers perceive and utilize inquiry in their classrooms. The findings related to the individual case reports fell into three main categories, a) definition of inquiry, b) inquiry planning, and c) inquiry enactment. Although these three teachers faced similar challenges when working with this student population and agreed on the importance of inquiry use in the classroom, these teachers held unique views on the implementation of inquiry. Alisa focuses primarily on doing science as defined by following the scientific method. Mariah holds a more teacher directed view on inquiry learning in the classroom. Although she agrees that questioning is an important factor, she focuses intently on how and to what degree students answer the posed question(s). Erica focuses primarily on the discovery aspect of inquiry. She explained the importance of building the capacity to think independently and critically and the role inquiry holds in the development of these skills. Leading with questions, working collaboratively, and fully explaining findings are crucial aspects of inquiry for Erica. Both cross case and individual findings gave a deeper account of how and why teachers, especially those involved in this project, view, plan, and enact essential features of inquiry.

Chapter V: Discussion, Implications, and Limitations

OVERVIEW

One goal of science education rests in supplying well-trained research and clinical investigators in order to support the demand for these careers in the 21st century. However, recent criticisms suggest the current environment in most science classrooms does not reflect real-word experiences related to science. Specifically, the most prevalent method of instruction centers on covering a vast breadth of information resulting in didactic interactions and the inability to apply this information outside of the classroom (Lee at al., 2007; ETS, 2009). Since the release of NRC (1996) and AAAS (1993) standards, there has been a greater emphasis on incorporating inquiry-based teaching in the classroom (NRC, 2012). The utilization of inquiry methods enables scientists to gain in-depth knowledge of specific domains through data analysis, interpretation and evaluation. Inquiry-based instruction incorporates these practices into classroom instruction allowing students to develop these skills and craft conclusions based on research and data. In response to this call for inquiry-based teaching, several federally funded initiatives have been introduced to support teacher need to adapt curriculum materials to foster student learning through inquiry-based practice (U.S. Department of Education, 2014).

The intervention from which this study was based is one of such initiatives. Teachers are challenged with implementing modules that are designed by researchers, engineers, and pre and in-service teachers. The intent behind this initiative was to raise both student and teacher knowledge and attitudes towards science through the use of inquiry based modules in the classroom. Teachers were afforded local and regional professional development opportunities each year to a) learn about new modules and b) participate in a hands-on demonstration of select modules based on grade level. However, it is important to note that there were several assumptions related to this project:

A. Teachers understand what is meant by inquiry,
B. Teachers know how to implement inquiry in the classroom, and
C. The modules that are given to teachers are, in fact, inquiry based.

Based on the 5E model, the module lesson plans were constructed with the intent of promoting the use of inquiry in the classroom. However, contrary to the underlying assumptions of the project, there were some discrepancies among teachers who plan to implement inquiry through their lesson plans and the actual use of inquiry in the classroom. Thus, the purpose of this study was to investigate the assumptions by: a) examining the extent to which teachers promote inquiry through classroom instruction and planning, b) how this instruction impacts student achievement, and c) examine the effects of teacher beliefs and perceptions on the use of inquiry-based instruction. Therefore, the following research questions were examined:

1. To what extent does inquiry use vary in the creation of a module versus a non-module lesson?
2. Do teachers who use modules demonstrate higher levels of inquiry planning and have higher achieving students?
3. What differences in teacher characteristics contribute to the varying use of inquiry in the classroom?

Discussion of Findings

Research Question One, Assumption A, and Assumption C

Therefore, to address research question one, a series of *t*-tests established if there is a statistically significant difference in the extent to which strategies that support inquiry were present in module lesson plans compared to teacher-developed lesson plans.

The intent of research question one was to determine if teachers were producing lesson plans with the same levels of inquiry as those created by the module developers. Specifically, the level of inquiry in each lesson was determined the 5E Lesson Plan Rubric (Goldston et al, 2010). Differences in the use of the 5Es were examined between module lesson plans and teacher-developed lesson plans. With the exception of the evaluate phase (Bybee, 2009) there were no differences found between the lesson plans created for sixth grade students by module developers and by teachers. However, there were statistically significant differences for seventh grade, all 5Es, with the exception of elaborate (Bybee, 2009) were greater for the project developed lesson plans.

Although the modules demonstrated greater incorporation of the 5Es than those of teachers, 5E use in terms of the explanation and elaboration stages is lacking significantly. For example, out of a possible 24 points for the explanation phase, module lesson plans obtained 11.67 (48.6%) points and 15.60 (65.0%) points on average for the sixth and seventh grade lesson plans, respectively. Compared to receiving 11.67 (73.0%) points and 13.64 (85.3%) points for the engage phase for sixth and seventh grade, respectively. According to the National Science Education Standards (NRC, 2012), inquiry-based teaching should focus on preparing students to think as real world scientists through "proposing explanations based on the evidence derived from their work." Therefore, even though both the module and teacher developed lesson plans score well on the engage and explore phases of the 5E Instructional Model; the areas most related to developing the skills of real world scientists (explanation and elaboration) were not represented strongly. Thus, the modules may not provide the full benefits related to inquiry-based teaching such as higher academic achievement (Amaral, et al., 2002; Chang & Mao, 1998; Jorgenson & Vanosdall, 2002; Von Secker, 2002) and positive attitudes towards science (Alouf & Bentley, 2003, Von Secker, 2002).

Research Question Two and Assumption B

This research question examined the potential differences of inquiry use in teacher-developed lesson plans of teachers who reported using modules (module users) as compared to those who do not (non-module users). The assumption underlying this research question centered on the notion that teachers who saw the value in the modules and were motivated to implement them in their classrooms, would exhibit greater adherence to the 5E Instructional Model in their authentic plans and result in better student outcomes (academic achievement [SAT-10, personal value of science, science interest, and inquiry strategies).

Differences in student outcomes (SAT-10, personal value for science, utility for science, inquiry strategies) were examined between teachers who used full or partial modules (module-users) and teachers who did not (non-module users). Differences between the 5Es present in lesson plans for the module and non-module users were also examined. The results of the analysis indicated that there were no significant differences between module and non-module users on inquiry use in the lesson plans, nor were there any significant differences for student outcomes.

Science interest, personal value for science, and SAT-10 achievement was slightly higher for module users (m=3.15, 3.72, 614.25, respectively) compared to non-module users (m=3.11, 3.68, 611.03, respectively), however, there was no statistically significant difference between teachers who used modules and teacher who did not. Previous research indicates that inquiry-based activities lead to increased science achievement (Amaral, et al., 2002; Chang & Mao, 1998; Jorgenson & Vanosdall, 2002; Von Secker, 2002) and students develop more positive attitudes toward science (Alouf & Bentley, 2003, Von Secker, 2002). So it is no surprise that there were no significant differences found between teachers who used modules and those who did not.

The results indicate that teachers, no matter if they use modules or not, are implementing inquiry (based on lesson plans) at similar levels. This gives way to the assumption that even though teachers see the value in using the modules, they are not necessarily utilizing inquiry practices in their classroom. These results lead to the next research question, which explores teachers' conceptions regarding their use of inquiry and case studies of inquiry implementation in the classroom.

Research Question Three, Assumption A, and Assumption B

The use of inquiry methods in classrooms is widely supported by researchers and educators due to the utilization of processes that allow students to mirror the mental and physical behaviors of scientists (NGSS, 2013; NRC, 2012). The need to increase the use of inquiry methods in classrooms spawned a series if science based intervention initiatives such as the MSP project from which this study is based (U.S. Department of Education, 2014). Due to the nature of this inquiry intervention, classroom teachers are primarily responsible for implementation. Therefore, seeing a need and a benefit for the intervention in tandem with the ability to do what is expected (utilize inquiry practices effectively) is critical.

Thus, research question three sought to identify relationships between teacher attributes (perceived need, perceived benefit, and 5Es) and the influence of these variances on the use of inquiry in the classroom. Correlational and multiple regression analyses were utilized to examine the effects of these variables on teacher orientations towards inquiry strategy use (AIS). Correlational data indicated inquiry strategy use had the strongest relationships with 5E score and perceived benefit. Therefore, the perceived need scale was not included in the regression analysis.

The regression analysis indicated the best predictor of inquiry strategy use was teacher orientations towards the 5Es, which lead into further examination of the 5Es. Since the composite 5E score was entered into model 1, each individual measure regarding the 5Es was then used to determine which of these phases best predicted use of inquiry in the classroom in model 2. Results indicated that explore, elaborate, and evaluate best predicted use of inquiry strategies. This finding is aligned with the previously discussed idea that the most critical aspects of inquiry are the latter phases. It is during these latter phases, namely explain and elaborate, that students are collecting data and comparing explanations in order to develop a deeper understanding of scientific phenomena. These findings support the idea that teachers believe that they, in fact, understand inquiry and implement inquiry strategies into their classroom. But, when a closer look of how teachers plan for inquiry based activities revealed actual use of inquiry strategies is limited.

In order to effectively plan for and implement inquiry practices in the classroom, sufficient experience, knowledge, and positive beliefs and attitudes regarding science is critical (Roehrig and Luft, 2004; Lederman, 1999). All three case study teachers' views of inquiry and what inquiry looks like oriented towards being more student centered when teaching. All three teachers agreed on the importance of students providing clear explanations of their findings and believed this practice led to a deeper understanding of scientific concepts. However, Alisa and Erica placed greater emphasis on students creating and exploring authentic questions and not did not focus primarily on verification of existing knowledge. These findings are aligned with those reported in a 2006 study by Bencze, Bowen, and Alsop where they found that teachers who practiced student-centered teaching had a greater tendency to utilize inquiry-based activities.

There was some discrepancy between the case study teachers' ideas and perceptions about inquiry and their actual use of inquiry in the classroom. These ideas about inquiry and their importance impacted instruction in varying ways. First, these teachers implemented full modules in their classrooms at a higher rate compared to their peers. Through examination of their attitudes and orientations, these teachers strongly supported the use of inquiry, however, their definitions of inquiry were limited and varied. There were instances where teachers felt as though they were implementing a particular feature of inquiry (i.e. giving students the chance to justify their results) however, their ideas regarding this feature was not aligned with what was intended. For example, during the implementation of a project module, Alisa indicated that students were given a chance to elaborate when each group shared their findings with another group. According the 5E model, this activity falls more in line with explanation phase since students are explaining their results with peers and determining the validity of their findings. This misconception related to the 5Es also ties back to the case study teacher ratings of essential elements of inquiry. Teachers may believe they are implementing all essential elements of inquiry although they are not. The perceptions these teachers hold are not unique to this project, studies of inquiry use and perceptions by both in-service and pre-service teachers have also shown this limited view of inquiry (Biggers et al., 2013).

Summary

Students must use existing knowledge in tandem with scientific reasoning and critical thinking in order to develop and expand existing knowledge (National Research Council, 2012). Compared to traditional methods of instruction, research has consistently demonstrated that students who are taught using inquiry-based methods are higher achieving in terms of academic competency and attitudes towards science (Chang and Mao, 1999; Prince, 2004). The use of strategies such as fostering problem solving skills, alternative explanations, communication, exploring, and construction of knowledge are all essential elements of scientific inquiry (Bybee, 2009). This study explored the relationship between the use of inquiry in classrooms, teacher orientations, and the potential effect on student achievement.

The framework of this project led to several assumptions. The Nanobio project provides access to intensive professional development where teachers are trained to utilize inquiry-based NanoBio modules in the classroom. The intention of these trainings rest in teachers learning how to use modules which advocate inquiry-based practices in their classroom which, in turn, would potentially produce a positive impact on student attitudes and achievement in science. However, in order for this framework to provide the intended results, several assumptions needed to be met:

A. Teachers understand what is meant by inquiry,
B. Teachers know how to implement inquiry in the classroom, and

C. The modules that are given to teachers are, in fact, inquiry based.

The findings indicate that these science teachers do understand the *importance* of science and they do place a high value on using inquiry strategies to facilitate student learning. However, there are some misconceptions and misunderstandings regarding the enactment of inquiry practices in the classroom. Inquiry methods, based on constructivist theories, require teachers to understand and interpret how students engage in critical scientific practices such as questioning, investigation, hypothesis-testing, and modeling (Biggers et al., 2013). Although teachers in this study believe they are implementing these strategies during their lessons, a close examination of lesson plans and classroom observations indicated a narrow use of inquiry in the classroom.

LIMITATIONS

The primary limitation of this study is the small sample size. Although over seventy teachers are participating in the NanoBio project, self-report measures were only available for less than half of the participants (n=29). The sample size was restricted more when lesson plans were solicited as only 18 teachers submitted those documents. However, the results showed there were some statistically significant relationships observed, thus leading to the need for further investigation. Even with a limited number of teachers, the utilization of the 5Es and inquiry strategies played a significant role in forecasting the use of student-centered approaches as demonstrated by the case study teachers. Although the sample size is small, the results of this study can begin to explain factors that may contribute to teacher inquiry use.

Another limitation of this study is the use of self-report measures by teachers and by students. All teacher assessments were typically administered at professional development sessions where they were being trained on newly developed modules. The use of self-report measures has the disadvantages such as inflation of rating measures and the tendency to gravitate towards socially desirable answers (Ganster, Hennessey, & Luthans, 1983; Podsakoff, MacKenzie, Podaskoff, & Lee, 2003). Also, the source of the lesson plans (teacher or module developed) reviewed by the evaluation team was known. Therefore, this method could have introduced some bias when scoring the lesson plans since the evaluators knew the module lesson plans were hypothesized to be more inquiry-based.

IMPLICATIONS

This study is a stepping-stone to identify important components of inquiry utilization success. This information can be useful when planning professional development sessions. Teachers are in need of training related to the conceptual framework regarding inquiry. Currently, when being introduced to a new module, teachers are typically given a brief overview of the concepts that are covered in the lesson, a materials list, and a brief hands-on session with the experimentation portion of the module. Inadvertently, this paradigm is enabling teachers to keep didactic views regarding scientific instruction while giving the perception of implementing inquiry. Hands on activities alone do not equate to inquiry-based learning. Professional developments should initially focus on expanding teachers' definitions and conception of inquiry before exposing them to inquiry based activities. Therefore, it is important to remain cognizant of how teachers develop their understanding of inquiry. As found by Kazempour (2009) and Larrivee (2008), teachers must be fully engaged in genuine inquiry experiences and given the opportunity to reflect on personal experiences in order to gain a deeper understanding and effective use of inquiry. So, it is not enough to passively learn inquiry based activities, teachers need to develop understanding and use of inquiry through practice and reflection. Thus, professional development opportunities should shift the focus from discussing modules and module activities to giving teachers sufficient time and opportunity to develop understandings, apply new skills, and reflect on how modules could possibly be modified to fit their needs while sustaining its integrity.

In a similar sense, provider readiness is often an overlooked element in regards to its importance in the successful implementation and sustainability of an intervention. The results of this study are line with previous research that highlights the importance of provider skills and perceptions in the successful implementation of an intervention (Durlak and DuPre, 2008; Greenhalgh et al., 2005 Fixsen, Naoom, Blasé', Friedman, and Wallace, 2005; Stith, Pruitt, Dees Fronce, Green, and Som, 2006). Specifically, Kallestad and Olewus (2003) reported individual factors such as provider perception as influential implementation factors. The finding that teacher perceptions in regards to perceived benefit and inquiry use are strongly related to inquiry strategies confirms these previous findings.

This implication is particularly important for educational program and intervention developers because teachers can be primarily responsible for implementation. Therefore, it is critical that teachers understand the purpose and goals of the intervention as well as possess the requisite skills needed to implement the intervention with fidelity. For this project, it is important for teachers to understand and possess a clear definition of what inquiry looks like. Therefore, when learning how to use inquiry based modules, there is a foundational understanding of how the materials can be used in the classroom. This foundation gives way for the intended goals of the project (increased positive attitudes and achievement in science for students and teachers) to be reached through inquiry practices. Also, when evaluating these sorts of programs, it is imperative for evaluators to consider the underlining assumptions (especially related to those primarily responsible for program implementation) that can have a significant impact on the progress towards the goals and programmatic outcomes. For this project, there was great emphasis placed on the use of modules to promote inquiry use in the classroom which, in turn, would impact teaching practices and lead to increases in student attitudes and achievement in science. However, there needed to be a full understanding of the module structure and use of inquiry and teacher understand of what inquiry looks like and the impacts inquiry can have on student achievement. As demonstrated by the case study findings, teachers have varying, often limited, ideas related to the primary component of the project (inquiry) which may have impacted the way the modules were viewed and utilized.

Teachers' voluntarily submitted lesson plans which they believed showcased high levels of inquiry and allowed researchers to observe the implementation of inquiry in their classroom. Interestingly, both the lesson plans and the observations indicated that teachers demonstrated similar trends during the engage and explore phases; however, there was a drastic decline in the elaborate and evaluate phases of the 5E model. It is during these phases that students make conceptual connections between new and former experiences, use what they have learned to explain a new object, event, organism, or idea, as well as draw reasonable conclusions from evidence and data and teachers use a variety of methods to assess student learning (Bybee at al. 2006). According the National Research Council (2000), inquiry, in terms of instruction, "refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world," (p.23). This raises questions about teacher perceptions and effectiveness when it comes to the use of inquiry. Teachers may believe they are conducting inquiry-based lessons, however they are lacking key components. These results raise questions about the alignment of teacher perceptions and actual use of inquiry.

It is important to note that confusion surrounding the term "inquiry" in reference to this pedagogy is not contained within this project. Ideas surrounding the meaning of "inquiry" have been the source of misperception for a long time (Schwab, 1962; NRC, 1996). Recently, NGSS adopted the term "scientific practices" in an effort to alleviate this confusion (Yager, 2012). This new term still emphasizes the need for students to engage in science practices that mirror those of real-life scientists, however, this framework identifies eight essential elements in a more clear process. The framework calls for students to be able to:

- Ask questions and define problems
- Develop and use models
- Plan and carry out investigations

- Analyze and interpret data
- Use mathematical and computational thinking
- Construct explanations and design solutions
- Engage in argument from evidence
- Obtain, evaluate, and communicate information

The new perspectives of how to engage in scientific practices includes eight explicit elements and are employed through all years of school (K-12) and gradually increase in complexity and sophistication as a student advances grades. Providing a clearer definition of what the focus of science education should look like may help disperse the common confusion that tends to surround the term "inquiry."

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the findings from this study, a stronger understanding of how teachers view essential features of inquiry is essential. Teachers seem to have a firm understanding of how to engage students and explore students' conceptions about phenomena, however, there is a clear misunderstanding of what is meant by providing students the opportunity to engage in the explain, elaborate, and evaluate features of inquiry. In addition, a subsequent study that would be beneficial is to determine the longitudinal effects of sustained inquiry use. Inquiry based practices have foundational principles related to problem solving, deep thinking, and analysis. These skills are useful in a broad range of domains from academic to social. In order to determine the long range effects of inquiry-based curriculums, tracking cohorts of students and determining their level of inquiry exposure, scholastic achievement, post-secondary choices, and career choices will be of substantial use. This would allow researchers the ability to demonstrate to key stakeholders and policy makers the need and benefit of inquiry use in classrooms and its potential effect on the economic climate.

Also, it is important to note that teachers who used modules during the year for this project (n=16), typically reported using 2 or less modules in their classrooms for the 2012-2013 year, some of which reported only using portions of modules (typically the hands-on activity or lab component). Therefore, there is a small treatment (use of modules) looking to cause a large effect (increased student achievement and attitudes in science). There are some confounding factors (e.g. other interventions, tutoring, parental support, etc.) that could have largely impacted teaching style and thus impacted student achievement. Therefore, to gain a better understanding of the actual impact that this type of intervention, it is suggested that a group of teachers are followed longitudinally. Initially, baseline data regarding skills, attitudes, and teaching practices (interviews and observations) should be collected. Subsequently, teachers should be observed and interviewed frequently in order to gain a clearer understanding of changes in teaching practices, if any, and what attributed those changes. Therefore, if there is an effect (e.g. student outcomes) there is a clearer connection between those outcomes and the treatment.

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APPENDIX A: PROTOCOLS

Interview Questions[2]

1. What types of lessons do you feel your students become really excited about? How so?
2. Do you have any particular strategies you use to get and keep students engaged? What are they?
3. How would you define inquiry? What does inquiry look like to you?
4. When planning an inquiry-based lesson, are there any particular strategies that you use?
    - Can you describe one of these strategies?
5. How often do you use inquiry when teaching?
6. How do you know you are using inquiry?
7. What is the most important aspect of inquiry based lessons?
8. How effective is inquiry in your opinion?
    - What are the benefits of inquiry?
    - What are the drawbacks?
9. What are some essential elements that should be present in an inquiry based lesson?
    - How important is it for your lessons to provide the opportunity for students to (rank):
        - Ask scientifically based questions?
        - Collect and use data to answer these questions?
        - Formulate explanations based on their data?
        - Compare their explanations to those of their classmates?
        - Justify their explanations?
10. How well do you believe the NanoBio modules fit with the definition of inquiry that you provided?
11. How well do the module lesson plans support the use of inquiry?
    - What would you change?

[2] *Denotes that teacher may be asked to reference a specific lesson when answering the question.

- What is working well?

12. What are some challenges you typically face when implementing inquiry in the classroom?*

13. Do you ever make changes to your original lesson plan once class starts?*

    - What causes these changes?

        - How do you recognize when this happens? What are your thoughts/strategies to revising or deviating from the original lesson plan?

    - How do you come to that decision?

14. Sometimes students ask interesting or challenging questions, how do you usually respond?*

    - What if you don't know the answer?

15. What aspects of your teacher training do you feel best prepared you for being a science teacher?

    - Describe how you were taught to present material to students.

    - How has this changed over the years?

    - In retrospect, is there anything that you wish you were taught/exposed to during your training?

16. In your opinion, what are some techniques that teachers can use to incorporate more inquiry into their classroom, especially when planning a lesson?

APPENDIX B- MODULE DESCRIPTIONS AND DATA

Sports Drinks and NanoTechnology (Alisa and Mariah)

This module centered on concepts related nanotechnology. The objectives of this modules were as follows: a) define nanotechnology and describe some of its real world applications and b) compare the concentration levels of electrolytes in every day sports drinks using nanogold particles as a biosensor. This lesson focuses on providing students with the opportunity to form a deeper understanding of the nano scale and nanotechnology and applying these concepts to real life. After an introduction to the nanoscale and how nanogold is used to determine the amount of electrolytes in a drink. Students first make predictions regarding which drink (water, sports drink, pickle juice, or lime juice) would be the best for restoring electrolytes to the body. This is followed by a discussion of why this information is important and applicable to real life. This module is aligned with one of the Alabama Course of Study Standards for eighth grade Physical Science and two National Science Standards:

Alabama Course of Study:

- Identify steps in the scientific process

National Science Standards:

- Understand the consequences of decisions affecting personal health and safety using nanotechnology
- Observe and describe changes in color of nanoparticle solutions

This lesson is structured using the 5E Instructional Model as follows:

- Engage (Day 1): Pre-Test, 3-D video on nanotechnology, observe a sample of nanogold, facilitated discussion
- Explore (Day 2): Make observations of samples (smell each liquid and attempt to identify). Discuss the meaning of a variable and control in an experiments. Identify variables and control of this experiment. Test each substance for electrolytes using nanogold and record data regarding the color of each sample.
- Explain (Day 2): Compare predictions to observed data. Exchange results with other classmates. Determine and discuss observed similarities and differences between results.
- Elaborate (Day 2): Interactive class discussions facilitated by teacher. Take home assignment
- Evaluate (Day 2): Post Test

Barn Owl Pellets (Erica and Alisa)

This module centered on concepts related to the interdependence of life and the complex interactions between different organisms that are required to sustain various ecosystems. The objectives of this modules were as follows: a) students will dissect an owl pellet; b) students will be able to identify various animal bones located within the pellet; and c) students will engage in an interactive class discussion centered on the barn owl, food chains, and food webs. This lesson focused on hypothesizing, predicting, 3-D presentations, collecting data (weighing and measuring), plotting collected data on graphs, and reconstructing and plotting bones found in the pellet. Due to the emphasis on various components of the life cycle including ingestion and biotic factors, this module is aligned with two of the Alabama Course of Study Standards for seventh grade Life Science and three National Science Standards:

Alabama Course of Study:

- Describe characteristics common to living things, including growth and development, reproduction, cellular organization, use of energy, exchange of gases, and response to the environment.

- Describe biotic and abiotic factors in the environment.

National Science Standards:

- The student will understand that within ecosystems, complex interactions exist between organisms and the physical environment.
- Animals eat plants or other animals for food and may also use plants (or even other animals) for shelter and nesting.
- Some source of energy is needed for all organisms to stay alive and grow.

This lesson is structured using the 5E Instructional Model as follows:

- Engage (15 minutes): Pre-Test and 3-D presentation
- Explore (75 minutes): Make hypotheses (what do barn owls eat?) and predictions (what will be found inside of the barn owl pellet). Collected and record data regarding the weight and size of the barn owl pellet and the number of bones (particularly skulls) found in the pellet. Compare predictions to observed data.
- Explain (30 minutes): Exchange results with other classmates. Determine and discuss observed similarities and differences between results.
- Elaborate (50 minutes): Interactive class discussions facilitated by teacher. Construct food chain.
- Evaluate (10 minutes): Post Test

Cell of Ozland (Erica)

This module centered on concepts related to the structure of cellular (eukaryotic) organelles and their functions. The objectives of this modules were as follows: a) students will understand how the structures of organelles all for their specific functions and b) students will gain an insight on the structure and various function of proteins. This lesson focused on providing students with hands-on activities to facilitate gaining deeper knowledge about organelles (hydrophobic and hydrophilic) and how their structure defines how they function.

This module is aligned with two of the Alabama Course of Study Standards for seventh grade Life Science:

Alabama Course of Study:

- Define eukaryotic cells, organelle, mitochondria, chloroplasts, and vacuoles

This lesson is structured as follows:

- Lead-In: students are separated in two groups before entering the classroom (hydrophilic and hydrophobic nanoparticles). Teacher will explain semi-permeability of the plasma membrane and how it relates to each of their groups. Students will rotate through three stations to learn about the differences between hydrophilic and hydrophobic.
- Class Time: Students go to different stations (nucleus, endoplasmic reticulum, and Golgi apparatus, mitochondria, and the lysosome) and learned how each of these function dependent on their group (hydrophobic vs hydrophilic) through worksheets and hands-on activities (DNA transcription, assembling proteins, etc.). Lastly, teacher led discussion based on class activity and clarified each step of the project and how it works in a real cell.

Closure: Teacher asked each group about their experiences and to explain how the structure of one organelle allowed for them to move to the next organelle.

Storm Chasers (Mariah)

This module centered on concepts related to various weather conditions, what causes them to happen, and their impact. The objectives of this modules were as follows: a) students will explore catastrophic events (tornado/hurricane) using mystery pieces (photos/objects); b) students will students will be able to explain various types of tornadoes, tornado season, impact of tornadoes (e.g. tornado alley), and how tornadoes are formed; and c) students will simulate a tornado; d) what is a hurricane, how are hurricanes formed, where do hurricanes happen, and how are they measured. This module is comprised of six distinct lessons that focus on one or more of the objectives listed above. Students work in typically work in groups and most lessons incorporated at least one hands-on activity (each lesson briefly described below).

This module is aligned with two of the Alabama Course of Study Standards for sixth grade Earth and Space Science and one National Science Standard:

Alabama Course of Study:

- Describe factors that cause changes to Earth's surface over time.
- Describe biotic and abiotic factors in the environment.

National Science Standard:

- Production and distribution of Writing-Use technology, including the Internet, to produce and publish writing and present the relationships between information and ideas clearly and efficiently.

This lesson is structured using as follows:

- Lesson 1: A Catastrophic Mystery: Introductory activity to understanding tornadoes and hurricanes. Students are separated into groups and given a bag or box with “clues” (pictures). Students use the clues to make predictions and form a summary about what they think might have happened in this catastrophic event. Students are given a news article to confirm their prediction.
- Lesson 2: Virtual Tornado: Students watched video explaining how tornados are formed followed by a class discussion. Students then complete a Webquest to explain how tornadoes are formed, evidence explaining tornado alley, tornado season, and measuring tornadoes.
- Lesson 3: Cooking Up a Storm!: Describe and explain the key factors that play a role in the formation of a tornado. Teacher explained key “ingredients” (factors) needed for tornado formation (anvil cloud formation, updrafts, supercells, funnel clouds). Students are then separated into groups and create recipe cards identifying key factors for tornado formation (may use notes, web, book, or any other supplemental materials).
- Lesson 4: The Perfect Storm: Students simulated a tornado by using 2 1-liter bottles, water, food coloring, lamp oil, and dishwashing liquid. During each step of the activity, students record observations related to the result of adding various ingredients to the bottles (i.e. food coloring,

Styrofoam balls, and dishwashing liquid). Students then attached the bottles together to create the tornado simulator.

- Lesson 5: Believe It or Not: The teacher explained the difference between a fact and myth. Students are divided into teams and the teacher facilitated an interactive game to determine if students know the difference between a tornado fact and myth.
- Lesson 6: The Virtual Hurricane: Students completed a Webquest to explain how tornadoes are formed, when is hurricane season, where do hurricanes happen, and how are hurricanes measured. Afterwards, the teacher leads a class discussion based on questions explored during the Webquest.

Modeling Mitosis (Alisa)

This module centered on concepts related to stages of mitosis and the processes related to each stage. The objectives of this modules were as follows: a) students will model mitosis to identify and describe the process in full or in any one of the stages; b) students will be able to recognize and sketch any stage of mitosis when given prepared slides of onion root or white fish blastula; and c) students will be able to explain mitosis to group members and model the process. This lesson provided three methods for learning about mitosis included creating models for each stage of mitosis with yarn and Popsicle sticks, preparing and examining slides containing their cheek cells and compare them to those of other students, and observing prepared slides of onion root tips and white fist blastula. This module is aligned with two of the Alabama Course of Study Standards for seventh grade Life Science:

Alabama Course of Study:

- Describe characteristics common to living things, including growth and development, reproduction, cellular organization, use of energy, exchange of gases, and response to the environment.
- Describe functions of chromosomes
- Identify functions of organelles found in eukaryotic cells, including nucleus, cell membrane, cell wall, mitochondria, chloroplasts, and vacuoles

This lesson is structured using the 5E Instructional Model as follows:

- Engage (110 minutes): Pre-Test, interactive class discussion based on questions provided in module packet, review parts of microscope and their respective functions, and human cheek cell lab[3].
- Explore (110 minutes): Students observed prepared slides of onion root tip and white fish blastula. Based on observations, students worked in groups to recreate one phase of mitosis using bulletin board paper, various colors of yarn, rubber bands and Popsicle sticks. Students completed Student Lab Guide which assessed student knowledge on topics such as haploids, chromosomes, and the different phases of mitosis.
- Explain (25 minutes): PowerPoint presentation with pictures, descriptions and questions to facilitate discussion based on the phases of mitosis.
- Elaborate (25 minutes): Taboo Genetic Vocabulary game and Karyotyping activity[4]
- Evaluate (10 minutes): Post Test

[3] No instructions included in packet on how lab should be completed.
[4] No description of either activity was provided in the packet.

All Modules Provided by Project

Alabama Course of Study Standard	Name of Lesson/Module
6.1 Identify daily Changes in weather based on the jet stream and global winds	Storm Chasers
6.2 Describe Factors that cause changes to the Earth's Surface Over Time	Storm Chasers
	Teaching the Properties of Waves through Real World Application
	The Rock Module
	Dynamic Earth: Cycling Rocks Naturally
6.4 Explain the plate tetonic theory	Rapping with the Plates
	Plate Tectonics: Slip Sliding Away
6.10- additional content- describing the life cycle of a star	What's In a Star?
6.10.1 Identify characteristics of the major components of the universe	Galaxy's Next Top Alien

Seventh Grade Modules

Alabama Course of Study Standard	Name of Lesson/Module
7.1 Describe characteristics common to living things, including growth and development, reproduction, cellular organization, use of energy, exchange of gases, and response to the environment	Barn Owl
	Modeling Meiosis and Gamete
	Osmosis and Diffusion
7.2 Identify functions of organelles found in eukaryotic cells, including the nucleus, cell membrane, cell wall, mitochondria, chloroplasts, and vacuoles	Cell of Ozland
	Finding the Nano in Trees
	Modeling Mitosis
	Nano in the Trees
	Osmosis and Diffusion
7.3 Relate major tissues and organs of the skeletal, circulatory, reproductive, muscular, respiratory, nervous, and digestive systems to their functions.	Self Assembly and Protein Folding
	Modeling Meiosis and Gamete
	Osmosis and Diffusion
	Self-Assembly in a Box for Teaching Tissue Organization at the Nano Scale
7.5 Identify major differences between plants and animals, including internal structures, external structures, methods of locomotion, methods of reproduction, and stages of development.	Plant's Nanomachinery
	Modeling Meiosis and Gamete
	Osmosis and Diffusion
7.8 Describe the function of chromosomes	Modeling Meiosis and Gamete
	Modeling Mitosis
7.7 Describe biotic and abiotic factors in the environment	Barn Owl
7.9 Identify the process of chromosome reduction in the production of sperm and egg cells during meiosis	Modeling Meiosis and Gamete
	Modeling Mitosis
	Modeling Meiosis and Gamete
7.10. Identify differences between deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).	DNA
7.11 additional content recognizing downs syndrome and sickle cell anemia as inherited genetic disorders. Using a monohybrid punnett square to predict the probably of traits passed from parents to offspring	Sickle Cell the Sticky Cell* escapades

Eighth Grade Modules

Alabama Course of Study Standard	Name of Lesson/Module	Creator
8.1 Identify the steps within the scientific process. Identifying examples of hypotheses	Abalone Shells	Virginia Davis, Shannon Bales, Lauren Rodriguez
8.6 Define solution in terms of solvent and solute	Nano-Structured Surface of Mentos	Christopher Easley
8.7 Describe the states of matter based on kinetic energy of particles in matter	The Mad Scientist	Michael Curry and Alicia Curry
8.10 Differentiate between potential and kinetic energy	Abalone Shells	Virginia Davis, Shannon Bales, Lauren Rodriguez
8.12 Classify waves as mechanical or electromagnetic	Nano in the Trees	Virginia Davis, Shannon Bales, Rachel Bostic
8.12 Describing how waves travel through media; Describing the electromagnetic spectrum in terms of frequency	Clean Energy: Nanoparticles, Chemical Reactions and Light	Shanlin Pan and Karen Boykin
	Nano Water Demo	Shanlin Pan and Karen Boykin

5E Lesson Plan Rubric Scores For Modules

Module	Grade	Engage	Explore	Explain	Elaborate	Evaluate
Galaxy's Next Top Alien	6	6	7	4	0	10
Plate Tectonics: Slip, Slidin' Away	6	16	15	16	5	15
Storm Chasers	6	15	14	12	3	13
Sports Drinks and Nanotechnology	6	16	14	13	2	11
The Rock Cycle	6	16	16	21	5	16
What's In a Star	6	14	12	14	0	13
Barn Owl Pellet	7	8	16	21	9	12
Cell of Ozland	7	12	8	6	2	8
DNA	7	9	14	7	1	9
Modeling Meiosis and Gamete Formation	7	15	13	16	4	13
Modeling Mitosis	7	15	13	16	4	13
Nano in the Trees	7	12	15	12	1	15
Osmosis and Diffusion	7	16	14	19	6	13
Plant's Nanomachinery for Photosynthesis	7	15	13	17	7	13
Self-Assembly and Protein Folding	7	14	13	16	9	16
Sickle Cell the Sticky Cell	7	11	11	8	2	11

Average 5E Lesson Plans For Modules and Teacher-Created Lesson Plans

		Sixth Grade		Seventh Grade	
		N	*M (SD)*	N	*M (SD)*
Engage	Teacher	24	8.58 (3.65)	24	7.70 (3.44)
	Project	6	11.67 (5.68)	10	13.64 (2.75)
Explore	Teacher	24	7.25 (4.09)	24	6.64 (3.68)
	Project	6	11.33 (4.80)	10	13.30 (2.21)
Explain	Teacher	24	7.50 (6.15)	24	6.96 (5.12)
	Project	6	11.67 (7.81)	10	15.60 (5.25)
Elaborate	Teacher	24	3.00 (3.00)	24	2.04 (1.17)
	Project	6	2.33 (2.33)	10	4.80 (2.10)
Evaluate	Teacher	24	4.50 (4.04)	24	4.75 (3.91)
	Project	6	11.67 (4.72)	10	12.60 (2.45)