Explicit Instruction of Scientific Explanation and Argument in an Undergraduate Introductory Biology Laboratory Course Using the Claim, Evidence and Reasoning Framework

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EXPLICIT INSTRUCTION OF SCIENTIFIC EXPLANATION AND ARGUMENT IN AN UNDERGRADUATE INTRODUCTORY BIOLOGY LABORATORY COURSE USING THE CLAIM, EVIDENCE AND REASONING FRAMEWORK

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The School of Education

by

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ABSTRACT

Scientific explanation and scientific argument are important aspects of science inquiry and science education. Though students of all ages find construction of written scientific explanations and arguments difficult, explicit instruction in scientific explanation and argument can improve student ability. This quantitative research study used a non-equivalent comparison group design to investigate the affect of explicit instruction of scientific explanation and argument in an undergraduate introductory biology laboratory course, using a college level appropriate modified CER Framework (McNeill et al., 2006). This study compared students receiving explicit instruction in scientific explanation and argument with students taking traditionally-designed biology laboratory courses. Students who received explicit instruction in scientific explanation and argument had significantly higher mean score increases from their pretest to posttest written scientific explanations and arguments. Additionally, students who received explicit instruction in scientific explanation and argument had significantly higher adjusted mean Colorado Learning Attitudes about Science Survey for Use in Biology (CLASS-bio) (Semsar, Knight, Birol, & Smith, 2011) posttest overall percent favorable scores, suggesting these students have more expert aligned views of biology as a discipline of science and the nature of science. Over the course of fourteen class meetings during the Fall 2013 semester, students receiving explicit instruction in scientific explanation and argument improved in ability to construct written scientific explanations and arguments. When constructing a model to explain student variation in ability to construct written scientific explanations and arguments biological content knowledge and explicit instruction were two influencing variable that contributed
significantly to the model. The results of this research study provide information on the role of explicit instruction in scientific explanation and argument in undergraduate introductory biology laboratory courses, and shows how to successfully include this valuable science inquiry practice into more traditionally designed laboratories often taught in larger universities.
CHAPTER 1.
INTRODUCTION

For the past three decades, scientists and science educators have called for improvement in undergraduate science and technology education, including reform of undergraduate biology education (American Association for the Advancement of Science [AAAS], 1989, 1990, 2011; Bransford et al., 2000; Howard Hughes Medical Institute, 1998; National Research Council [NRC], 1999, 2003, 2009; National Science Board [NSB], 1986; National Science Foundation [NSF], 1996). Reform of introductory undergraduate courses is especially critical. The first two years of undergraduate education are important for retaining and recruiting Science, Technology, Engineering, and Mathematics (STEM) majors. In February 2012, the President’s Council of Advisors on Science and Technology (PCAST) presented a report highlighting the need to produce an additional one million STEM graduates who will become STEM professionals over the next decade, of which approximately one in ten STEM professionals will become life scientists or technicians. This report predicts the number of STEM degrees earned needs to increase by 34% (PCAST, 2012, p. 1), to fulfill these positions over the next decade. Approximately 75% of the STEM professionals required to fill positions over the next decade could be produced by increasing the retention rate of students who enter college intending to major in a STEM field from 40% to 50% (PCAST, 2012, p. 1). Reforming introductory STEM courses to engage and inspire students has the potential to increase retention of students intending to major in STEM fields and potentially attract non-STEM majors to major in STEM fields (AAAS, 2011; National Research Council (NRC), 2003; PCAST, 2012). Additionally, STEM professionals and “STEM-capable” workers have
access to some of the best jobs in the economy with higher wages and lower unemployment rates (PCAST, 2012).

Non-STEM majors, including K-12 educators, are usually exposed to undergraduate STEM courses during the first two years of college, making introductory level courses critical for STEM education of all undergraduates. It is not uncommon for introductory courses to be the last formal science education an individual receives, potentially contributing to a lifelong attitude toward science and hopefully advancing the science literacy of the non-STEM majors (AAAS, 2011; PCAST, 2012). Undergraduate introductory courses and science education in general, should promote development of students’ scientific reasoning and quantitative literacy skills, which includes the use of inquiry, evidence, and core concepts, aspects of scientific literacy, which allow all individuals to enjoy the natural world and intelligently participate in science and technology-related topics that have a direct impact on society and the quality of life in the 21st century (AAAS, 1989, 1993, 2011; Ebert-May, Speth, & Momsen, 2010; Handelsman et al., 2004; NRC, 1996; National Science Foundation [NSF], 2009).

The NRC describes similar skills needed for student who plan “to successfully undertake careers in research after graduation, students will need scientific knowledge, practice with experimental design, quantitative abilities, and communication skills” (NRC, 2003, p.2). Scientific and technological advances have changed the way biological research is conducted in the 21st century. Real world observations and societal issues need to be addressed with interdisciplinary and integrative research approaches (NRC, 2003, 2009). These research approaches require undergraduates to learn how to use, apply, and analyze concepts across levels of organization and complexity, across
fields within biology, and across science, technology, engineering, and mathematics (STEM) disciplines (AAAS, 2011; NRC, 2003, 2009).

Both the *National Science Education Standards* (NRC, 1996) and the recently published, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), which is meant to provide a framework for the development of new National Science Education Standards, stress the importance of science as inquiry. Student construction of scientific explanations and scientific arguments are important practices of science inquiry (NRC, 1996, 2012). In grades 9-12, “identifying questions and concepts that guide scientific investigations,” “formulate and revise scientific explanations and models using logic and evidence,” “recognize and analyze alternative explanations and models,” and “communicate and defend a scientific argument” are considered fundamental abilities necessary to do scientific inquiry (NRC, 1996, p175-6). *A Framework for K-12 Science Education* further explains one of the essential practices of science as using reasoning and argument for clarifying strengths and weaknesses of a line of evidence to identifying the best explanation for a natural phenomenon, and defending explanations by formulating evidence based on a solid foundation of data, examining understanding in light of evidence, and collaborating with peers in searching for the best explanation for the phenomenon being investigated (NRC, 2012).

Though constructing scientific explanations and arguments is essential in science inquiry and therefore, science education (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; McNeill, Lizotte, Krajcik & Marx, 2006; McNeill & Krajcik, 2008), constructing scientific explanations and arguments is often omitted in classroom practices
(Newton, Driver, & Osborne, 1999). This is unfortunate, because constructing scientific explanations and arguments is difficult for students and adults, especially articulating and coordinating claims and evidence through reasoning (Bell & Linn, 2000; Driver et al., 2000; Kuhn, 1991; Nussbaum & Sinatra, 2003; Nussbaum, Sinatra, & Poliquin, 2008; Osborne, Erduran, & Simon, 2004; Saddler, 2004; Sandoval & Millwood, 2005; Stark, 2005; Stark, Thomas, & Krause, 2009). However, explicit instruction of scientific explanations and arguments and use of appropriate evidence can help students construct better scientific explanations and arguments (Lizotte; McNeill, & Krajcik, 2004; McNeill, 2009; McNeill & Krajcik, 2008; Nussbaum et al., 2008; Osborne et al, 2004; Sadler, 2004; Zohar & Nemet, 2002).

Understanding the nature of science, and how scientific knowledge is generated is also an important aspect of science literacy and a goal of reform efforts (AAAS, 2011; NRC, 1996, 2012; Sandoval, 2003). Student construction of scientific explanations and arguments provides an opportunity for students to participate in activities and thinking processes of scientists, and to better understand inquiry and the nature of science and how it results in socially constructed scientific knowledge (AAAS, 2011; Bell & Linn, 2000; Duschl & Osborne, 2002; Nussbaum et al. 2008). Too often content knowledge and processes of science inquiry are taught separately (NRC, 2006), by teaching science content in the context of science inquiry, students learn how the content knowledge is generated and are better able to apply the science content to novel situations (AAAS, 2011; NRC, 2012). Student construction of scientific explanations and arguments has also been shown to enhance content knowledge and use of scientific principles in
reasoning (Bell & Linn, 2000; Berland & Reiser, 2009; McNeill et al., 2006; Zohar & Nemet, 2002).

Though adults and undergraduate students have difficulty constructing scientific explanations and arguments and coordinating claims and evidence through reasoning (Kuhn, 1991; Stark, 2005; Stark et al., 2009), little research has investigated constructing scientific explanations and arguments at the college level, especially in introductory biology laboratories. The available research on instruction in scientific explanation and argument at the college level has taken place in educational methods courses using biology, chemistry and physics content, and there is research showing use of argument and explanation in biochemistry and chemistry courses as well (see Scientific explanation and argument in undergraduate courses in Chapter 2: Literature Review). However, the majority of research on constructing scientific explanations and arguments has focused on elementary, middle, and secondary students (see Scientific Explanation and Scientific Argument in Chapter 2: Literature Review), perhaps because K-12 education has been the focus on national science education standards.

McNeill et al., (2006) have designed an instructional framework aligned with science education standards to promote student construction of scientific explanations and arguments about phenomena in which claims are justified by appropriate evidence and scientific principles for the K-12 level. Their instructional framework is modified from Toulmin’s (1958) model of an argument and includes three parts: claim, evidence, and reasoning and is referred to as the CER Framework (McNeill et al., 2006). The CER Framework has been used across science disciplines including biology, chemistry, and physics and age levels including elementary, middle, and secondary school classes (see
The claim, evidence and reasoning instructional framework for construction of scientific explanation and scientific argument in Chapter 2. Literature Review.

McNeill et al.’s (2006) CER Framework will be modified to be college level appropriate for use in this research study. For older students McNeill and Martin (2011), recommend including the fourth component of rebuttal along with claim, evidence and reasoning. Berland & McNeill (2010) constructed a learning progression showing the levels of scientific explanation and argument from simple to complex. Though the learning progression is based on experience with construction of scientific explanations and arguments and content knowledge and is not age dependent (Berland & McNeill, 2010), to make CER Framework college level appropriate, students will be instructed to produce written scientific explanations and arguments at the more complex end of the learning progression. A complex scientific explanation and argument includes the following: (a) “claim addresses question with causal account,” (b) “claims are defended with evidence and reasoning,” (c) each “component (i.e. evidence, reasoning, and rebuttal) is appropriate and sufficient,” and (d) “counterclaims are rebutted” (Berland & McNeill, 2010, p. 770, Figure 1). These descriptions have been included in the Scientific Explanation and Argument Base Rubric (SEABR, see Appendix 1), which has been modified from the McNeill et al. (2006) CER Framework base rubric to be college level appropriate. The SEABR will be used in this study to assess college level student’s written scientific explanations and arguments.

In this research study, the college level appropriate modified CER Framework (McNeill et al., 2006) instructional model for construction of scientific explanations and arguments will be incorporated during more traditional “cookbook” laboratories that are
so common in large research universities to increase the level of inquiry in the laboratory activity and potentially promote understanding and meaning making of science content and the nature of science. The instructional context of these laboratory activities is on the less complex end of Berland and McNeill’s (2010) learning progression: the laboratory activities include questions with only two to three answers and small data sets only including appropriate data will answer those questions. However, simplifying the instructional context can result in students constructing more complex written scientific explanations and arguments (Berland & McNeill, 2010).

**Research Objectives**

The purpose of this quantitative study is to implement the CER Framework as an instructional model for student construction of written scientific explanation and argument in an undergraduate introductory biology laboratory course at a large university in Southeastern United States. This study will compare students receiving instruction in scientific explanation and argument with students taking traditionally-designed biology laboratory courses, investigate the progress of students’ construction of written scientific explanations and arguments over the course of the semester, and explore the influence of demographic and academic variables on students’ ability to write scientific explanations and arguments by addressing the following three research objectives and associated questions.

**Objective 1**

The first objective is to compare how explicit instruction in scientific explanation and argument and traditional instruction of biology laboratories affects students. Student ability to construct written scientific explanations and arguments, student biological
content knowledge, student ability to write a lab report, and student perception of biology as a discipline of science will be addressed by answering the following questions:

a) Will explicit instruction in scientific explanation and argumentation improve student ability to construct written scientific explanations and arguments after completion of laboratory activities or experiments, over students instructed through traditionally-designed laboratories?

b) Will explicit instruction in scientific explanation and argumentation improve student biological content knowledge, over students instructed through traditionally-designed laboratories?

c) Will explicit instruction in scientific explanation and argumentation improve student ability to write formal lab reports, over students instructed through traditionally-designed laboratories?

d) Will explicit instruction in scientific explanation and argumentation influence students' perception of biology as a discipline of science, over students instructed through traditionally-designed laboratories?

**Objective 2**

The second objective is to evaluate student progress of written scientific explanation and argument over the course of the semester. Students receiving explicit instruction in scientific explanation and argument write six arguments over the course of the semester, which will be evaluated by answering the following question:

a) Will students’ ability to write scientific explanations and argument continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)?
**Objective 3**

The third objective is to attempt to explain variation in student ability to construct written scientific explanations and arguments. Various demographic and academic variables can influence student ability to construct written scientific explanations and arguments by and will be investigated by answering the following question:

a) What demographic and academic variables positively influence student ability to construct scientific explanations and arguments?

As discussed above, it is not uncommon for undergraduate introductory courses to be the last formal science education an individual receives. Construction of scientific explanation and argument, an important component of science inquiry, in undergraduate introductory science courses can provide an opportunity for undergraduates to engage in scientific inquiry and promote science literacy (AAAS, 2011; NRC, 1996, 2012; PCAST, 2012). Though difficult for all students, including undergraduates and adults, construction of scientific explanations and arguments can be taught through explicit instruction using a framework such as the CER Framework (Lizotte; McNeill, & Krajcik, 2004; McNeill, 2009; McNeill & Krajcik, 2008; Nussbaum et al., 2008; Osborne et al., 2004; Sadler, 2004; Zohar & Nemet, 2002). Student construction of scientific explanations and arguments has been shown to promote student understanding of the nature of science (AAAS, 2011; Bell & Linn, 2000; Duschl & Osborne, 2002; Nussbaum et al. 2008) and can result in increased content knowledge understanding (Bell & Linn, 2000; Berland & Reiser, 2009; McNeill et al., 2006; Zohar & Nemet, 2002).

Unfortunately, explicit instruction of scientific explanation and argument is often omitted in science education (Newton, Driver, & Osborne, 1999). The majority of research has
focused on K-12 science education and there is little research at the undergraduate level in construction of scientific explanations and arguments, especially in introductory biology laboratory courses (see Scientific Explanation and Argument in Chapter 2: Literature Review). However, this research study can fill that void in the research as it addresses the role of explicit instruction of scientific explanation and argument in undergraduate introductory biology laboratory courses.
CHAPTER 2.
LITERATURE REVIEW

This quantitative research study is investigating the effects student construction of written scientific explanation and argument in an undergraduate introductory biology laboratory course. When investigating the influence of an instructional practice on students it is important to understand and be aware of the theoretical basis of the instruction practice, why the instructional practice is important, and the instructional practice. The theoretical basis of student construction of written scientific explanation and argument is constructivist as students are using evidence and reasoning to construct meaning of natural phenomena. Joseph Novak’s Human Constructivism has a similar view of learning as cognitive science and is ideal for use in science education. Scientific literacy has become a major goal of science education and driver of reform in science education for the past four decades. An understanding of and ability to construct written scientific explanation and argument can promote scientific literacy in students. Human Constructivism, scientific literacy, and scientific explanation and argument are discussed below.

**Human Constructivism**

Novak’s Human Constructivism views meaning making as both a theory of learning and an epistemology to construct new knowledge (Mintzes & Wandersee, 1998). A theory of learning attempts to explain how “humans learn their usable knowledge” (Novak, 2010, p.90), while epistemology is concerned with ways of knowing, the origin of new knowledge, and the structure of that knowledge (Davis, 2009; Novak, 2010). A Human Constructivist view of the nature of science lies between the logical-positivist view of the nature of science as “an objective effort to understand natural phenomena
through direct observation of the physical world,” and the radical constructivist view that “reject(s) entirely the notion that scientific knowledge can be tested against an external reality” and the social constructivist view that “reality itself is simply the process of social negotiation (Mintzes, Wandersee, & Novak, 1998, p. xviii). Ernst von Glasersfeld (1987) describes radical constructivism as a theory that knowledge does not come from a knowable external reality, instead knowledge is constructed from human experience organizing and making sense of reality. Lev Vygotsky’s (1962) work in social constructivism stresses the importance of language in knowledge construction and learning. For Human Constructivists there is an external and knowable natural world where human beings act as meaning-makers through interactions with objects, events, and other people, therefore making the goal of education to construct shared meanings of the natural world (Mintzes et al., 1998). The origins of Human Constructivism and Novak’s work has built on and can be understood by considering developmental psychology, psychological learning theory, the work of Jean Piaget, Jerome Burner, Joseph Schwab, and Robert Gagne (Mintzes & Wandersee, 1998). The writings and work of these four men influenced both David Ausubel’s Assimilation Learning Theory and Novak’s Human Constructivism.

Jean Piaget and Cognitive Development Theory

Piaget, a Swiss scientist, began his research in biology by investigating the phylogeny of mollusks, but soon became interested in the study of cognitive development in children. Paiget’s theory is based on the development of cognitive operational capacities or structures that he believed applied across subject matter domain. The biological process of learning takes place over time as cognitive capacities or general
reasoning capacities change through the processes of assimilation, accommodation, and equilibration. Assimilation results when new learning fits into an existing cognitive operational structure, while accommodation results when new learning requires modification to the operational structure, and equilibration of the cognitive operational structure follows as balance is gained in the new operational structure (Mintzes & Wandersee, 1998; Novak, 1977a, 2010).

In *The Language and Thought of the Child*, Paiget (1926) described the transition of these cognitive capacities through four developmental stages through interaction with physical objects in the environment. Stage 1 is the sensory-motor period in which children from birth to two years manipulate physical objects in the environment and eventually recognize the permanence of objects through a cognitive reality as they respond to objects not physically present. Stage 2 is the preoperational period in which children ages two to seven years develop the ability to use mental symbols to represent things or events in the environment. At this time the child shows an egocentric view of the world, and cannot see objects or events from another perspective limiting explanations to their personal experiences. Stage 3 is the concrete operational period in which children ages seven to eleven years use concrete props to compare, contrast, predict, and explain real things. Though the child no longer has an egocentric view of reality, the child cannot reason hypothetically. Stage 4 is the formal operational period in which children ages eleven through adulthood make inferences and predictions on hypothetical cases as well as concrete events or objects observed. Continued language development increases the ability of individuals to manipulate mental constructs and draw connections between mental constructs (Paiget, 1926).
Paiget’s work has been called psychological constructivism and has shown how an individual’s engagement in the world and biological development results in the learning of concepts and construction of knowledge (Davis, 2009; Matthews, 1994). In the 1960’s Paiget’s developmental theory became popular in science education as research studies supported that older students were more successful at certain tasks than younger students, resulting in specific recommendations for curriculum based on the cognitive operational capacity required for understanding topics and instructional strategies (Matthews, 1994; Novak, 2010). However, Paiget’s theory of development has been criticized for excluding (a) prior experiences and knowledge of the learner (Mintzes & Wandersee, 1998), (b) the role of school learning on the stages of development (Novak, 2010), and (c) concept and propositional learning in specific knowledge domains (Ausubel, Novak, & Hanesain, 1978; Novak, 1977a, 2010). The criticisms have been addressed in the Ausubel's and Novak’s work.

Jerome Bruner

Bruner, a professor of psychology and the Director of Cognitive Studies at Harvard, became well known to science educators when he wrote “any subject can be taught effectively in some intellectually honest form to any child at any stage of development,” in his most influential work, The Process of Education (1960, p. 33). Bruner further stated that basic concepts must be taught first in a concrete manner before including formal explanations and logic. Bruner also emphasized the importance of the organizational structure of topics in a discipline in school teaching, so that students can learn how the concepts are meaningfully related. Additionally, in science disciplines, students should engage in scientific inquiry to learn the analytic skills of scientists and to
engage students in the material. Bruner argued intrinsic interest in a discipline is the best way to motivate student learning (Mintzes & Wandersee, 1998). These ideas contributed to Bruner’s discovery learning model of instruction, which he is thought to have originated in the early 1960s; however his ideas of learning by doing are similar to earlier writers, including John Dewey. *The Act of Discovery* (Bruner, 1961) suggests discovery learning allows students to acquire information in a manner that promotes prompt retrieval for future use in problem solving, because students use their prior experience and knowledge in a teacher constructed discovery to organize knowledge in a meaningful way.

**Joseph Schwab and Teaching Science as a Process of Inquiry**

Schwab influenced the use of inquiry in science education curriculum reform in the early 1960’s. Schwab’s contributions encouraged teaching science as a process of inquiry by using open-ended laboratory investigations to teach students to observe, ask questions, record data, and develop conclusions (Mintzes & Wandersee, 1998). His ideas contributed to the Biological Sciences Curriculum Study for high school biology reform and later were incorporated into curriculum development for all the natural sciences in elementary and middle school as well (Mintzes & Wandersee, 1998). In 1973 Schwab identified “four commonplaces” that he considered to be necessary when trying to understand and design educational instruction: learner, teacher, subject matter, and social matrix. This construction has influenced educators including Novak and his theory of education (Novak, 2010).
Robert Gagne and the Process Skills Approach to Science Teaching

Gagne also supported the inquiry method. He initially focused on elementary level science education, contributing to the American Association for the Advancement of Science, *Science: A Process Approach* (1963-1983), a curriculum that was designed to teach elementary students science process skills like observing, classifying, etc. Eventually, the science process skills approach was expanded to intermediate and upper grades where more advanced process skills like measuring, predicting, controlling variables, and interpreting results were incorporated into the learning tasks. This process skills approach was based on Gagne’s “hierarchy of learning levels” that he described in *The Conditions of Learning* (1965) and was based on stimulus-response behavioral learning (in Novak, 1977a). Gagne argued the importance of the mastery of small conceptual units first, and then building to the more general and inclusive units. He stressed that the specific hierarchy of learning tasks was needed to design instruction (Novak, 1977a). Though Gagne incorporated many hands-on activities to teach process skills, he is criticized for his approach of first teaching small ideas then building to general ideas, because a top down approach where students are introduced first to general, inclusive topics, provides a framework for understanding as in Ausubel’s Assimilation Learning Theory (Mintzes & Wandersee, 1998; Novak, 1977a).

David Ausubel’s Cognitive Assimilation Theory of Learning

However, Ausubel’s ideas were not well known or accepted in the early 1960s, and they had little influence on curriculum development at this time (Mintzes & Wandersee, 1998; Novak, 1977a, 2010). He had difficulty publishing his work and receiving acknowledgment for his learning theory that was based on a constructivist epistemology, where learners must construct their own concepts or knowledge. Ausubel’s theory conflicted with behavioral psychology that is based in a positivistic epistemology that there is one “truth” that can be discovered by observation, that was at its peak in the 1960’s (Novak, 1977a, 2010).

Ausubel first developed and discussed his theory as “cognitive learning” in the 1960’s (Ausubel, 1963, 1968), but in the second edition of Educational psychology: a cognitive view (1978) Ausubel and his colleagues called his theory of learning “assimilation theory”. The revised title highlights the importance of assimilation, which is the linking a new idea with relevant prior knowledge that will modify both the new idea and the prior knowledge (Ausubel et al., 1978), and prior knowledge in learning. Ausubel (1968) is frequently quoted for his statement: “The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.” an idea that is critical for meaningful learning (p. vi).

Meaningful learning is the central idea in Ausubel’s theory (Mintzes & Wandersee, 1998; Novak, 1977a, 2010). In order for meaningful learning to occur, three conditions must be met: (a) the learner must have relevant prior knowledge that new ideas can be associated with; (b) the new knowledge must contain meaningful concepts, rather than nonsense syllables; and (c) the learner must choose to relate the new knowledge to the prior knowledge. When meaningful learning occurs, hierarchical
cognitive structures are developed in a top down approach where more specific concepts are linked with more general concepts (Mintzes & Wandersee, 1998; Novak, 1977a, 2010). This process of organizing new more specific concepts with prior more general concepts is called subsumption and will modify the meaning of both concepts and the cognitive structure of an individual. Even if the learner cannot describe the details of the specific new concepts, which is called obliterative subsumption, the overall cognitive structure, or prior knowledge, which was modified by the new knowledge, is still enhanced and allows for similar specific knowledge to be learned more easily.

Superordinate learning occurs when the learner gains new, more general and inclusive topics that are overarching ideas that illuminate a domain of knowledge and often results in the restructuring of the learner’s cognitive structure. Progressive differentiation occurs as concepts become more precise resulting in highly branched, hierarchical cognitive structures through subsumption and superordinate learning. Integrative reconciliation can also occur during meaningful learning when cognitive structure is further modified as similarities and differences between related concepts are incorporated. Integrative reconciliation will lead to further progressive differentiation of concepts (Ausubel et al., 1978; Mintzes & Wandersee, 1998; Novak, 1977a, 2010). In order to help the learner connect new knowledge with prior knowledge, Ausubel recommends the use of advance organizers, an instructional strategy that promote meaningful learning. Advance organizers provide a general overview prior to an instructional unit (Novak, 2010).

Ausubel also distinguishes between meaningful learning and rote learning in his cognitive assimilation theory. While meaningful learning results in development of complex cognitive structures, rote learning results in memorization of isolated facts.
Once these isolated facts are forgotten, they no longer contribute to learning and can even inhibit future learning (Novak, 2010). Unfortunately rote learning is common in school learning, as teachers present facts to students, who are expected to recite them back on various types of tests. Rote learning is often associated with reception learning, giving reception learning a bad name and stimulating the discovery or inquiry learning reform of the 1960s, which suggests that meaningful learning can only occur when students discover knowledge on their own (Mintzes & Wandersee, 1998). However, Ausubel and colleagues (1978) argue that the rote learning-meaningful learning continuum and the reception learning-discovery learning continuum are two independent dimensions. Reception learning is critical in school learning as students cannot discover in 10-15 years of school knowledge that has taken mankind centuries to acquire, and not all discovery learning is meaningful as shown by Gagne’s hands-on approach, which lacked structure for science concepts. Ausubel’s Cognitive Assimilation Theory argues reception learning can be meaningful when subsumption, obliterative subsumption, superordinate learning, progressive differentiation, and integrative reconciliation are used to guide students to create hierarchically organized cognitive structures (Ausubel et al., 1978; Mintzes & Wandersee, 1998).

**Joseph Novak and Human Constructivism**

Novak began his career with doctoral research in science education investigating problem solving in college-level botany and later developed an audio-tutorial teaching approach used in colleges, secondary schools, and elementary schools. Novak used the audio-tutorial teaching approach to study science learning. Novak was introduced to Ausubel’s Cognitive Assimilation Learning Theory and Bruner’s cognitive theory, which
he found supported and explained conclusions from his studies (Mintzes & Wandersee, 1998). Novak’s career continued with a research program in science education focused on developing a learning theory to be applied to classroom or school learning in the hopes that education could become more like science and be guided by theories and principles (Novak, 1998).

Novak and his colleagues (1972) used audio-tutorial lessons to teach elementary school students abstract science ideas including the particulate nature of matter, energy transformations, food chains, and earth and gravity. After the instruction, the elementary students were able to use highly formal reasoning when discussing the learned science concepts, which shows cognitive development at the formal operational period in Piaget’s theory of developmental psychology, a period development Piaget argued children do not reach at least until age eleven. According to Piaget, elementary aged students are either in the preoperational or concrete operational periods of cognitive development. Novak argued that though Piaget has greatly contributed to educational psychology, his theory of developmental psychology does not best explain school learning, rather Ausubel’s cognitive assimilation theory of meaningful learning can better support a theory if education (Novak, 1977b).

Novak first published his ideas in A Theory of Education (1977a), and the ideas were further developed and rewritten in Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations, which was first published in 1998 and the second edition was published in 2010. Novak called his theory of education Human Constructivism, which he argues is both a theory of learning and an epistemology to acquire new knowledge (Mintzes & Wandersee, 1998; Novak, 1998,
Human Constructivism is based on Ausubel’s Cognitive Assimilation Theory and meaningful learning, which focuses on development of hierarchical cognitive structures or cognitive learning. However, in Novak’s view of Human Constructivism, thinking or cognitive learning, feeling or affective learning, and acting or psychomotor learning all contribute to an individual making meaning of learning experiences (Novak, 2010). Additionally, the interactions between five basic elements of education including learner, teacher, knowledge, context, and evaluation, of which the first four are based on Schwab’s commonplaces of education, should be considered as they will contribute to the meaning of an experience for an individual (Novak, 2010).

Novak’s Human Constructivism describes human beings as meaning makers in which meanings are constructed by forming connections between new concepts and prior knowledge through the process of meaningful learning. No two individual will construct the same meanings as the learner, teacher, knowledge, context, and evaluation will always be different. Therefore, to a Human Constructivist, the teacher’s role is to actively engage students and negotiate shared meanings so learned concepts and core principles can be discussed (Mintzes & Wandersee, 1998). As Human Constructivism is both an epistemology for new knowledge acquisition and a learning theory, the same cognitive processes of meaningful learning used by discipline experts during breakthrough research are used by in school learning. Novak argues through meaningful learning complex knowledge structures are developed that allow for creativity; especially when superordinate learning occurs allowing overarching concepts to become clear, which can result in the most creative breakthroughs in a field (Novak, 2010). Though few are acknowledged for being extremely creative, all individuals have some level of
creativity that can be developed through meaningful learning (Mintzes & Wandersee, 1998; Novak, 2010). Not only does meaningful learning enhance creativity, it also provides organized knowledge structures that increase problem solving and the ability to acquire more new knowledge than students who learn isolated facts via rote learning (Novak, 1977a, 1977b, 2010).

**Cognitive Science and Implications for Education**

Cognitive science, which emerged in the latter half of the twentieth century and began influencing science education in the 1970s, uses an interdisciplinary approach to investigate human thinking and learning. These disciplines include anthropology, linguistics, philosophy, developmental psychology, computer science, neuroscience, and several additional branches of psychology which utilize qualitative and experimental approaches to test theories on thinking and learning (Bransford, Brown, Cocking, Donavan & Pellegrino, 2000; Mintzes & Wandersee, 1998).

In 2000, the National Research Council Commission on Behavioral and Social Sciences and Education, including the Committee on Developments in the Science of Learning and the Committee on Learning Research and Educational Practice published *How People Learn: Brain, Mind, Experience, and School: Expanded Edition* (Bransford et al., 2000). *How People Learn* (Bransford et al., 2000) focuses on research in cognitive science investigating human learning that can be used to design formal instruction from kindergarten through college level. This cognitive research on human learning was meant to improve education to help all individuals reach full potential. In order for individuals to reach full potential, education should provide opportunities to develop understanding of subject matter and learning strategies allowing individuals to be lifelong
learners. In 1996, Herbert Simon acknowledged that it is no longer important to just remember the facts, rather “knowing” means an individual can find and use the vast amounts of information available to everyone (Bransford et al., 2000).

*How People Learn* (Bransford et al., 2000) discusses the cognitive science research implications for improvement of education highlighting three key findings: (a) preconceptions of students must be engaged or new concepts learned will not be incorporated into daily thinking, rather the new concepts will be remembered for assessment and forgotten; (b) competence in an area of inquiry requires a foundation of factual knowledge in a conceptual framework that allows the student to retrieve and apply that knowledge; and (c) a metacognitive approach to learning allows students to take control of learning goals and self-assess progress toward reaching them (Bransford et al., 2000). These key findings are congruent with meaningful learning as described by Ausubel’s Cognitive Assimilation Theory and Novak’s Human Constructivism (Ausubel et al., 1978; Novak, 1977a, 2010), and are based on cognitive science research investigating human memory systems and comparison of novice and expert knowledge structures topics that can lead to a better understand the information processing of the human mind.

**Human Memory Systems**

The brain is composed of hundreds of billions of neurons, a type of cell with thousands of branching dendrites and axons which form synapses, or points of contact with other neurons, that provide a physical network for active mental functions and memories. The role of individual neurons is not fully understood. One view suggests individual neurons represent one unit of memory or property of the unit giving memories
“local” representation (Bowers, 2009), while the more popular “distributed” representation suggests individual neurons can contribute to many units of memory, the focus of a unit of memory is on the pattern of neurons activated (McClelland, 2011).

Neurons in different regions of the brain are associated with different functions in memory. The limbic system, located on the medial side of each cerebral hemisphere, is associated with learning, memory, and emotion. One structure of the limbic system, the hippocampus is thought to form and organize short term memories (McClelland, 2011; Novak, 2010). However, the hippocampus is not capable of storing memories; the cerebral cortex, or the thin layer covering the surface of the brain, which contains 75% of the neurons in the brain, will store long term memories as new synapses are formed between neurons (McClelland, 2011). The amygdala, another structure of the limbic system, is thought to form emotional responses from sensory stimuli and store memories (Novak, 2010). There is a strong connection between memory and emotion, emotion can prompt memory, and emotional memories are often associated with and stored in memory networks (Nalbantian, Matthews, & McClelland, 2011).

Cognitive scientists view the human mind as an elaborate information processing mechanism in which the human memory system includes a sensory input or perceptual memory, short term or working memory, long term memory, (Atkinson & Shiffrin, 1968 in Wandersee & Mintzes, 1998) and emotional memory ( Nalbantian et al., 2011; Novak, 2010). Sensory input is detected by associated structures of the brain, and is almost immediately forgotten unless there is conscious effort to process the information. As the sensory perception is processed it becomes incorporated in short term memory where it will remain for as long as it is necessary to perform a task, approximately 15 to 20
seconds, though similar sensory input can recovery short term memories after a few hours. The capacity of short term memory is thought to be around seven pieces of information (Miller, 1956). Random numbers or letters, with no meaning would each be considered a piece of information. However, as letters form words or phrases with meaning, the words or even the phrases can be considered a piece of information, and more can be remembered in short term memory (Novak, 2010). It has also been shown that words are easier to remember if accompanied by a picture (Roediger, 1997 as cited in Bransford et al., 2000). Conscious attempts to impose structure, interpret, compare, and connect pieces of short term memory with information stored in long term memory will slowly build connections between the two by modifying an individual’s cognitive knowledge structure to incorporate new information in the existing knowledge structure potentially resulting in meaningful learning (Bransford et al, 2000; Novak, 2010). This process results in the physical remodeling of synapses between neurons to facilitate transmission of the memory along a network of neurons (Bransford et al, 2000; McClelland, 2011). Emotion also contributes to the human memory system. Emotional memory can be a conscious memory of an emotion, or an unconscious emotion occurring during the formation of a memory (Nalbantian et al., 2011; Novak, 2010).

The human mind does not act as a passive recorder of events; rather all of the components of the human memory system interact. Long term memory, or an individual’s existing knowledge structure, influences what sensory input is acknowledged by the brain and therefore processed as pieces of short term memory. The existing knowledge structure provides meaning for pieces of information, influencing the size of the pieces of information that can be stored in short term memory at one time. Past
experiences and existing knowledge structure also influence how new knowledge stored in short term memory is processed, organized, and connected to existing knowledge (Bransford et al., 2000; Novak, 2010). Emotional experiences and memories can also influence sensory input, short term memory, and long term memory in a similar manner (Novak, 2010).

Additionally, experiences that did not happen in the real world can also influence human memory, when mental activities, such as processing, categorizing, and inferring are incorporated in the memory of an experience. For example, when given a list of words commonly associated with the concept “sweet,” it highly likely for the word “sweet” to be included in the list of recalled words. The mental processes used to remember the list of words included using the word “sweet,” and when “sweet” was also remembered is suggests the mental process was incorporated into the memory, though “sweet” was not part of the original experience (Roediger, 1997 as cited in Bransford et al., 2000). A second example shows the discussion of an event over time eventually resulted in children remembering the non-experience as though it had occurred. Though the children initially admitted the event did not exist, the mental activities involved in discussion of the non-event were incorporated into a memory of the experience (Ceci, 1997 as cited in Bransford et al., 2000). These non-experience memories stimulate the same regions of the brain as experienced memories and can influence the human memory system in the same way as real world experiences (Bransford et al., 2000).

When meaningful learning occurs, the cognitive structure of an individual is modified as information stored in short term memory is processed and stored in long term memory. The human mind uses past experience, which can include prior knowledge
already stored in long term memory, emotional memory, and mental activities, to provide structure for new knowledge and experiences. As the cognitive structure of the mind is altered, the physical structure of the brain is also altered as new synapses are formed between neurons making it easier for those neurons to communicate with each other as learning occurs (Bransford et al., 2000).

**Expert Knowledge Structures**

Providing structure for knowledge as it is stored in long term memory is critical for learning, especially if the knowledge is to be retrieved and used in novel situations such as problem solving. The knowledge structure of discipline experts, who can readily apply their knowledge to novel problems, can be used to better understand important characteristics of the structure and use of knowledge in problem solving, which has the potential to be applied to learning environments. Cognitive scientists have found that expert structure and use of knowledge in a variety of disciplines including chess, history, mathematics, and life and physical sciences have similar characteristics. First, expert knowledge structures are highly organized in a hierarchical and interconnected framework of concepts. A hierarchical organization of knowledge allows experts to see the large meaningful patterns in their domains. When experts are presented with a problem, they first determine the overarching concept is being addressed to solve the problem (Bransford et al., 2000; Chi, Glaser, & Farr, 1988). Due to the organized and interconnected framework of expert knowledge structures, knowledge related to the overarching concept is accessible for use in solving the problem. Cognitive scientists refer to knowledge organized in a hierarchical framework as “conditionalized” knowledge (Bransford et al., 2000). The hierarchical and interconnected framework of a
discipline expert mirrors the hierarchical and interconnected cognitive structure resulting from meaningful learning described in Ausubel’s Cognitive Assimilation Theory and Novak’s Human Constructivism, especially the idea of superordinate learning where knowledge is organized around more general and inclusive overarching ideas that illuminate a domain of knowledge (Ausubel et al., 1978; Novak, 1977, 2010).

Understanding of expert knowledge structure suggests the importance of providing students with opportunities to experience superordinate learning and identify large meaningful patterns, in developing a hierarchical and interconnected framework of knowledge (Bransford et al., 2000).

Though experts excel in their domains, the ability of an expert to transfer their knowledge to problem solving in other domains is limited (Chi et al., 1988). However, experts are able to transfer problem solving abilities to unknown topics within their domain of expertise, as the overarching, meaningful patterns used to solve a problem are the same so experts can quickly identify what is needed to solve a problem (Bransford et al., 2000). Strong metacognitive skills, or self-monitoring skills, another characteristic of experts, allow experts to quickly determine what knowledge is lacking or erroneous. Metacognitive skills contribute to expert ability to transfer knowledge to solve novel problems (Bransford et al., 2000; Chi et al., 1988). Adaptive experts view new situations as a chance to increase their expertise. These experts use metacognitive skills to continually question their knowledge levels, and improve their understanding resulting in lifelong learning, an ideal goal in education. The limited ability of experts to transfer knowledge to solve problems outside of their domain, also suggests that though experts may know subject matter in their discipline, they are not necessarily experts at teaching
that subject matter to others. Expert teachers in a discipline have pedagogical content knowledge; they are aware of concepts students have difficulty learning and can assess existing knowledge, which is required for meaningful learning, as well as progress made from meaningful learning (Bransford et al., 2000).

Scientific Literacy

Scientific literacy is considered a major goal of science education and has been an important consideration in educational reform for the past four decades (AAAS, 1989, 1993, 2011; NRC, 1996). However, scientific literacy has not always played such an important role in the reform of science education. The following will first discuss an overview of the history of undergraduate science education, and when scientific literacy became a recognized term and influential in science education reform. Second, scientific literacy and its various aspects will be discussed.

An Overview of the History of Undergraduate Science Education

Political, social, economic, and/or military issues have long influenced science education curriculum reform in the United States (Mintzes & Wandersee, 1998). Throughout the history of science education, reform tends to swing back and forth between the need for an academist elite undergraduate science education, which is heavily focused content knowledge and structure of the various disciplines of science, and a practicalist or progressive view of science education, which provides science education for the masses using a curriculum focusing on societal issues and applications of science (DeBoer, 1991; Montgomery, 1994). Though this pendulum of reform has swung from one side to the other several times over the past 200+ years, there has been a trend toward the a practicalist or progressive view and the importance of scientific
literacy for all Americans for the past four decades (AAAS, 1989; DeBoer, 1991). The common occurrence of reform in science education is discussed in the following overview of the history of undergraduate science education in the United States of America, which ends with the influence of scientific literacy in science education.

Benjamin Franklin and Thomas Jefferson first introduced science courses to the curriculum of higher learning in an attempt to establish a distinct form of American education as early as the American Revolution. By the end of the 18th century, most colleges taught a number of science disciplines including natural history, botany, and chemistry. However, science courses were secondary to the classical disciplines of languages, mathematics, and philosophy and were often taught by mathematics or philosophy professors. Though in 1790, John Maclean was the first science professor hired by an American college, Princeton, which was called the College of New Jersey at the time (Montgomery, 1994).

Between 1820 and 1840, industrial development in the United States popularized science for the general public and college reforms began to increase the number of science courses in the curriculum. First, geology, mineralogy, and physics classes were introduced, and later in the 1850s, biology became a discipline, with distinct courses in zoology, botany, and agriculture in the next decade. These courses were taught by scientists working for universities. These scientists were hired as educators with the goal of training new scientists and advancing American science, but from the 1840s onward, scientific research became the main focus of these professor scientists as academia became the home of American science. These academic scientists helped to develop the
American Association for the Advancement of Science (AAAS) in 1846 adding another level of professionalism to science (Montgomery, 1994).

Though reform in the 1820s and 1830s introduced science to college curriculums, students were not able to earn a college degree in the sciences, and studying science did not have the same status as studying the classical disciplines. In the 1840s, Yale had a scientific school, which was isolated from the rest of the college. The Sheffield Scientific School, as it was named in 1861, provided a scientific education through practical and laboratory training. Harvard and Dartmouth had similar scientific schools, Lawrence Scientific School and Chandler Scientific School respectively. These scientific schools established contemporary science within colleges and universities, but science education was still considered second to the classical disciplines of languages, mathematics, and philosophy (Montgomery, 1994).

Technical colleges were also introduced during this time of industrial development including Renssealaer Polytechnic Institute in 1824 and restructured in 1851, Ohio Mechanics College in 1828, and Cooper Union in 1859. These schools focused on teaching scientific agriculture and practical training to produce engineers and scientists for work in industry. The technical colleges were often funded by industrialists and merchants with the practicalist view that education should be utilitarian and technical training in science was the best way to advance society (Montgomery, 1994).

The Morrill Act of 1862 established land grant colleges thereby further promoting the use of science to solve agricultural and technological problems. Every state was awarded 30,000 acres of land for each senator and state representative in congress to found colleges, which lead to the founding of many existing state colleges and
universities. These land grant colleges were to provide both liberal and practical education through classical studies as well as science, focusing on agriculture and mechanical arts. Initially, land grant colleges focused on the applied sciences of agriculture and mechanical arts, but by the mid 1880s, these colleges began to shift toward more traditional higher education with the curriculum focused on the pursuit of knowledge instead of vocational training (Montgomery, 1994).

Andrew Dickson White, president of Cornell College, and Daniel Coit Gilman, president of Johns Hopkins College, contributed to the shift in curriculum on the pursuit of knowledge as they attempted to model their institutions after German universities. White focused on undergraduate education by providing equal status to humanities courses and science courses, which required students to perform experiments in laboratories. However, Gilman focused more fully on the pursuit of knowledge through research laboratories and removed the undergraduate program altogether in the 1870s. As land grant colleges followed the examples of Cornell and John Hopkins, they attempted to incorporate laboratories for pure knowledge production resulting in the development of research universities during the 1880s and 1890s (Montgomery, 1994).

As White and Gilman were transforming Cornell and John Hopkins, Charles W. Eliot worked to reform the curriculum at Harvard College. As the President of Harvard College from 1869 to 1895, Eliot worked to incorporate science study into the curriculum, arguing it is as important and not in conflict with literary studies, and eventually included the once separate scientific school in the college (Montgomery, 1994). He believed science should be taught through the study of the physical world, rather than through book study. Eliot stressed the importance of the laboratory method of
science teaching and training in scientific thinking (DeBoer, 1991). Eliot also worked to advance science education at secondary schools, as well as colleges. Eliot chaired the Committee of Ten in 1892, appointed by the National Education Association (NEA) along with other university presidents and secondary school principals, in an attempt to standardize college admission policies and secondary school college preparatory curriculum. The committee recommended that students preparing for college should follow a curriculum where one fifth of secondary education focused on natural sciences and included the importance of introducing all branches of science through extended lab periods and field trips rather than book science and rote learning (Mintzes & Wandersee, 1998). Though Eliot worked to advance science education, his views of higher education were conservative and based on a new Academism, a new liberal arts curriculum including modern languages, literature, history, and science, to develop and discipline the minds of future leaders (Montgomery, 1994), and his work in secondary school science education focused on preparing students for a college education (Mintzes & Wandersee, 1998).

In addition to laboratories at land grant colleges funded by the Morrill Act researching pure and applied knowledge, new universities funded by the industrial elite including John D. Rockefeller, Cornelius Vanderbildt, and Andrew Carnegie had laboratories researching both basic and applied science. In the 1890s, academia was the source of American science, the origin of new knowledge. Joseph Rice furthered the importance of science in education, after studying in Germany with the famous psychologist Wilhelm Wundt, when he argued there was a need for a “science of education” and a “progressive school” based in the ideas of science (Montgomery, 1994).

During the first decade of the 20th century, efficiency and management influenced academia and higher education through the development of academic departments including physics, chemistry, biology, and geology, a rank scale for faculty, and a credit system to quantify student progress. With the development of academic departments, the faculty of the various departments became the experts in that discipline, as they were the source of knowledge and the dispensers of knowledge. The faculty in a department influenced curriculum decisions and established course requirements for students majoring in that field. Positivism became the standard in higher education as experts sought the truth and then enlightened students and citizens through education (Montgomery, 1994).

As enrollment in colleges and universities jumped from approximately 150,000 in 1900 to more than 1.2 million in 1922, the natural sciences significantly expanded (Montgomery, 1994), and colleges and universities began to produce experts to work in industrial society as urged by the progressive movement to base curriculum on society’s needs. However, the academist teaching of “pure” science was still significant.
Therefore around 1915, most colleges and universities had two curriculums, one for future professional scientists and one for nonscientists. Future scientists often studied from textbooks, which included contributions and ideas of great minds in the discipline, and laboratory activities that replicated those famous experiments or participated in original research to train for careers. While the curriculum for nonscientists included a general science course, in which science subjects were taught using everyday principles and basics of scientific thinking including the importance of observation and evidence, and a laboratory course exposing students to everyday experiments. Due to the low opinion research scientists had of teaching general science courses, often incoming faculty with the least teaching experience taught general science and survey courses. Though the nonscientists’ curriculum was meant to provide science for the large number of students enrolled in colleges and universities, there was a distinct division elevating professional science from “science for society” (Montgomery, 1994).

In the 1920’s Harvard developed an honors programs to separate elite students with potential to continue in academia from the masses of regular students. Many other colleges and universities divided the four year undergraduate curriculum into junior college and senior college in attempts to separate the students with the most potential from the majority of the students, who did not progress beyond the first two years. Junior college, the first two years, was filled with general education and survey courses. Survey courses in the sciences were often taken by nonscience majors and presented basic concepts, discoveries, and experiments of the discipline and were supported by very simple laboratory activities. Teaching during the progressive era viewed the teacher as a lecturer presenting a standardized curriculum to the masses (Montgomery, 1994). On the
other hand, senior college provided upper level course work for professional development and specialization. Often senior college science courses included research apprenticeships at federally funded laboratories for future scientists (Montgomery, 1994).

These divisions in the curriculum especially senior college research apprenticeships, prevented science education for future research scientists from being affected by the Progressive reform during the 1920s through the 1940s. Secondary science education shifted after the report of the Commission on the Reorganization of Secondary Education (National Education Association, 1918 as cited in Mintzes & Wandersee, 1998) recommended a curriculum should meet social needs and science education should focus on hygiene, electronic appliances, industry and household chemistry, and practical aspects of nature providing life skills to the public (Mintzes & Wandersee, 1998). Junior college and non-major courses providing “science for society” illustrate efforts of the Progressive reform.

After the launch of the Soviet spacecraft Sputnik, on October 4, 1957, there was public concern that American education had become too soft, focusing too much on learning isolated conclusions through rote learning and once again there was a call for science education reform (Mintzes & Wandersee, 1998; Novak, 2010). Americans wanted the education system to produce world-class scientists and engineers, and curriculum design was put in the hands of scientists who focused on the structure of scientific subject matter and methods of scientific investigation taught through rigorous text books and laboratory activities. New secondary education science courses were developed to teach the various branches of natural science including the Physical Science Study Committee, the American Chemical Society developed the Chemical Bond
Approach and the Chemical Education Material Study course, and The Biological Science Curriculum Study produced three versions of its course (Mintzes & Wandersee, 1998). Funding from the National Science Foundation supported disciplinary experts in “teacher-proofing” the curriculum to bypass the lack of scientific knowledge of classroom teachers. Scientists grounded their reform efforts in developmental psychology, psychological learning theory, and the work of Piaget, Burner, Schwab, and Gagne (Mintzes & Wandersee, 1998).

However, by the end of the 1960’s it became apparent that these new science education courses failed to meet social goals of science teaching and the new theme of science literacy became a discussion topic for science educators (Deboer, 1991). Educators critiqued the reforms that were in response to Sputnik as being too focused on the “structure of the discipline” attempting to educate only the few educational elite, who would become research scientists. Science educators instead wanted a science curriculum concerned with the varying abilities of all students to educate all citizens to be knowledgeable on science issues pertaining to student interest and socially relevant issues (DeBoer, 1991). This shift in educational focus in the 1970’s from intense discipline guided curriculum to a socially relevant science curriculum as similar to the Progressive reform era of the 1920’s and 1930’s, so Diane Ravitch referred to the movement as New Progressivism (DeBoer, 1991).

Paul DeHeart Hurd of Stanford University was one of the first educators who used the term “science literacy.” He described science literacy as the understanding of science and its applications to society, especially the role of technology in society, which had become so influential, that social values, issues, and educational goals could not be
discussed without referring to science (DeBoer, 1991). However other professors and academics at the time felt science literacy described a greater content knowledge of a broad range of science disciplines, and very few discussed issues of the social aspects of science. Another view of science literacy included the skills and knowledge needed for citizens to read science issues discussed in the popular media (Koelsche, 1967 as cited in DeBoer, 1991). By the late 1960s, the term “science literacy” was used in research articles to mean, relationship of science and society, science and technology, which are both similar to Hurd’s description, conceptual knowledge similar to the ideas of some professors and academics, the nature of science, the ethics of science, and the role of science in the humanities (DeBoer, 1991). Though there were many different understandings of science literacy, it became clear that science literacy focused science education to include more than the discipline focused curriculums of the 1950s, that like Hurd discussed, science is an influential aspect of society and science should be taught in a social context (DeBoer, 1991).

In the 1970s, the National Science Teachers Association [NSTA] stated that science literacy is the most important goal of science education. The NSTA (1971) defined science literacy as the ability to use “science concepts, process skills, and values” in everyday decisions dealing with other people and the environment and an understanding of relationships between “science, technology, and other facets of society, including social and economic development” (p.47-48). Further the NSTA (1971) wanted science curriculum to consider objectives that would be useful to thoughtful lay citizens, and increase student interest in science and science investigations.
Reform seems to be a continuing theme in science education, and once again in the 1980’s there was a call for science education reform. This time the reform efforts seemed to be driven by the decline of the American economy and concerns over consistent decline in quality of American public education that was becoming apparent in education studies and reports presented to the public by the mass media (AAAS, 1989). One famous report, *A Nation at Risk* (National Commission on Excellence in Education [NCEE], 1983) discussed the avoidance shown by American students for science and mathematics, the low test scores in science and mathematics, low rankings on international studies of students’ knowledge of science and mathematics, and easier learning standards for American students compared to other countries. The failures the American economies were associated with the failures of the public education of science and mathematics, suggesting an increase understanding of science and mathematics for all Americans was desired (AAAS, 1989).

In the 1980s, the American Association for the Advancement of Science put together a committee that was meant to promote lasting reform of science education. In 1989, *Science for All Americans* provided a “set of recommendations on what understandings and ways of thinking are essential for all citizens in a world shaped by science and technology” (AAAS, 1989, p. v), and described science literacy, the importance of science literacy, and path to achieving science literacy. In 1993 the AAAS and Project 2061 presented *Benchmarks for Science Literacy*, identifies how students should progress from kindergarten through high school graduation in mathematics and science education to become scientifically literate adults, by providing grade level benchmarks for knowledge and skills associated with science literacy.
Science for All Americans (AAAS, 1989), Benchmarks for Science Literacy (AAAS, 1993), along with The Content Core (NSTA, 1992) were important publications leading to the development of national standards for science education. The NRC organized a committee including representatives from various groups including the American Association for the Advancement of Science, the National Science Teachers Association, American Chemical Society, National Science Resources Center, the American Association of Physics Teachers, the Earth Science Education Coalition, and the National Association of Biology Teachers, which produced and the National Science Education Standards (NRC, 1996). The NRC is currently heading a committee working on producing the Next Generation of Science Standards: (Public Release II, NRC, 2013), which continues to focus on the importance of scientific literacy in K-12 science education through disciplinary core ideas, science and engineering practices, and crosscutting concepts.

While national science education standards for undergraduate education have never been established, the National Science Foundation, National Research Council, American Association for the Advancement of Science, the National Science Teachers Association, and the Howard Hughes Medical Institute have all published reports calling for reform in science education. My research focuses on undergraduate biology education, so I will address three recent reports specifically addressing the science discipline of biology. BIO 2010: Transforming Undergraduate Education for Future Biologists (NRC, 2003), as stated in the title is focused on education of biology majors. However this report still coincides with aspects of science literacy recommending students need to learn concepts across disciplines of science including biology,
chemistry, physics, and mathematics, because science is interdisciplinary in nature, and science inquiry skills allowing students to answer questions and solve problems. It recommends students learn through interdisciplinary project-based activities where content and skills can be actively learned and that present more real world questions and problems scientists need to address (NRC, 2003). A New Biology for the 21st Century (NRC, 2009) suggests the focus of biology in the 21st century should addressing social issues including food supply, development of alternative forms of energy, conservation of the environment, and development of preventative individualized health care. Additionally, any technology that may help to addresses these issues should be given priority. Though A New Biology (NRC, 2009), like BIO 2010 (NRC, 2003), focuses on biology majors rather than all undergraduate students, A New Biology calls for the creation of interdisciplinary curricula, graduate programs, and teacher training programs aimed to help solve these interdisciplinary social issues, which align with the scientific literacy. Vision and Change in Undergraduate Biology Education: A Call to Action (AAAS, 2011) focuses on providing an undergraduate biology education for all students. Vision and Change is centered on ideas of science literacy and even identifies one of their goals as biological literacy. Biological literacy can be reached when students learn core concepts and competencies for disciplinary practice. Vision and Change (AAAS, 2011) stresses that students can learn these concepts and competencies, by presenting specific examples of these concepts and use of competencies in a detailed manner, rather than presenting a general overview of a large amount of biology content knowledge, this is referred to as focus on depth-over-breadth. Additionally, there is potential for all undergraduates to obtain some degree of biological literacy and therefore science literacy,
when these concepts and competencies are presented through student-centered instructional practices and scientific teaching, where assessment of student learning outcomes inform instructional practices (AAAS, 2011). Science literacy has had a critical focus in science education reform for over 40 years for both K-12 and undergraduate science education.

**Scientific Literacy**

Scientific literacy is an important goal of school science education (AAAS, 1989; NRC, 1996). Science education, and therefore science literacy, should prepare students to think for themselves and contribute to a just society as the future of the nation and the world will be influenced by human use of science and technology (AAAS, 1989). The *National Science Education Standards [NSES]* define scientific literacy as “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity” (NRC, 1996, p. 22). There are many aspects of scientific literacy, which both *Science for All Americans* (AAAS, 1989) and the *National Science Education Standards* (NRC, 1996) address. These aspects include: a greater understanding of the natural world including key concepts and principles of the physical, life and earth sciences; the interconnectedness of the many disciplines of science; the nature of science; the human aspects and limitations of science; and the ability of thinking scientifically, which includes asking and answering questions about the world, identifying science issues in the media and political world, and evaluating arguments and conclusions they draw using evidence gathered by valid methods and from valid sources (AAAS, 1989; NRC, 1996).
Teaching scientific literacy in schools science and having a scientifically literate society has many advantages for society. First, scientifically literate citizens have a greater understanding of the world around them, which provides empowerment, fulfillment, and excitement about the world (NRC, 1996). Science and technology have an increasing role in society, and citizens need to be able to address questions in their everyday lives regarding societal science issues. Including the use, management and distribution of shared resources, like air, water, and national and rain forests; a scientifically literate society will be able to make informed decisions and consider the interdependence of living things and the decrease in biodiversity on the physical environment (AAAS, 1989; NRC, 1996). Other societal problems that can potentially be solved through science and technology include population growth, disease, and pollution (AAAS, 1989). Additionally, scientifically literate individuals are able to use inquiry skills, including critical analysis of claims and arguments, to address claims and arguments presented by the mass media, teachers, other authority figures, peers, and others to determine the validity of claims, arguments, and evidence to be considered, which can reduce prejudices and misunderstandings of individuals and society (AAAS, 1989). The business world needs entry level workers who are scientifically literate and able to learn, think creatively, and use quantitative information and logical arguments to make decisions and solve problems. These skills of scientifically literate workers will allow students to hold meaningful and productive jobs. Additionally, keeping up with the global economy requires scientific literacy for creative development of novel technology and scientific knowledge (AAAS, 1989; NRC, 1996)
The nature of science and scientific knowledge. Science is a process for producing knowledge that values empirical evidence, logical reasoning, and doubt and criticism (AAAS, 1989; NRC, 1996). Through observation and experimentation scientists develop theories that attempt to explain natural phenomena. Theories that are able to explain a larger number of observations and are supported with a higher number of empirical cases are more powerful and tend to develop and become more defined over time (AAAS, 1989). However, not all theories will remain unchanged overtime; scientific knowledge is dependent of evidence and observation. New observations can challenge theories, which will be modified and sometimes discarded, and there is always the chance a new theory can better explain a larger amount of evidence (AAAS, 1989; NRC, 1996). Because scientific knowledge is based on observation and evidence and is constantly changing, scientist do not believe they can uncover the absolute truth, rather scientists are working to determine increasingly more powerful theories to explain the natural world around us (AAAS, 1989).

Science is a human endeavor, and individuals and teams of individuals throughout history have worked to increase the base of scientific knowledge (AAAS, 1989; NRC, 1996). Science is a social activity, and therefore reflects social values. As culture has changed throughout history, so has science (NRC, 1996). There was a time when women and minorities were not allowed to be scientists, and aspects of science found interesting specifically to these people were probably not addresses. Societal norms also influenced the questions scientists addressed and found to be important. Funding agencies, government, universities, and industries also have an influence on the topics felt to be important and addressed by scientists (AAAS, 1989). Scientists as human also have
ethical traditions including accuracy, openness, replication, and peer review. Additionally research should be moral and scientists must prevent harm from coming to animal and human research subjects (AAAS, 1989; NRC, 1996). Scientists attempt to be free of bias, however scientists are human so personal, business, and community needs can influence their decisions (AAAS, 1989).

**Scientific inquiry.** The processes that scientists follow to gain scientific knowledge can be described as scientific inquiry. There is not one set of steps that scientists follow, instead scientists vary by discipline on how they collect data, the type of data collected, and the types of questions asked (AAAS, 1989; NRC, 1996). However, all scientists work to collect data that will be used to validate scientific claims or explanations through the development of arguments using of logic and reasoning (AAAS, 1989). Scientific explanation and scientific argument are discussed in detail in the following section.

**Scientific Explanation and Scientific Argument**

Both scientific explanation and scientific argument are important aspects of science, science inquiry, and, therefore, science education (Duschl & Osborne, 2002; NRC, 1996; Newton, Driver, & Osborne, 1999; Sandoval & Millwood, 2005). Scientific explanation and scientific argument are discussed in important science education literature leading to the development of national standards, including *Science for All Americans* (AAAS, 1989) and the *National Science Education Standards* [NSES] (NRC, 1996), *A Framework for K-12 Science Education* [*A Framework*] (NRC, 2012), and the *Next Generation Science Standards: Public Release II* [NGSS] (NRC, 2013).
NSES (NRC, 1996), A Framework (NRC, 2012), and NGSS (NRC, 2013) include science skills and processes addressing scientific explanation and scientific argument. The NSES include “Science as Inquiry Standards’ to present skills that introduce students to the processes of science, which are combined with scientific content knowledge to promote a greater understanding of science and address “abilities necessary to do scientific inquiry,” which at the 9-12 level include: (a) formulate and revise scientific explanations and models using logic and evidence, (b) recognize and analyze alternative explanations and models, and (c) communicate and defend a scientific argument (NRC, 1996, p. 175-6). A Framework and NGSS include practices, which are modified from science process skills found in the NSES and designed to allow students opportunities to practice building science knowledge and promote understanding of why and how science knowledge is evaluated and modified after being constructed (NRC, 2012, 2013; Reiser, Berland, & Kenyon, 2012). Two of these practices include: a) constructing explanations (for science) and designing solutions (for engineering) and b) engaging in argument from evidence (NRC, 2012, p. 68-9, 73).

**Scientific Explanation**

Science for All Americans (AAAS, 1989) describes scientific explanations as statements that attempt to make sense of observations of natural phenomena. Scientific explanations can have a broad or limited scope and must be “consistent with currently accepted scientific principles,” “incorporate a body of scientifically valid observations,” and be “logically sound” (AAAS, 1989, p. 7). The NSES address the idea of scientific explanation in the context of science inquiry and science learning describing scientific explanations as a student or scientist the incorporation of “existing scientific knowledge
and new evidence gained through observation, experimentation, or models into internally consistent, logical statements” (NRC, 1996, p. 117). The NSES also describe the scope of scientific explanations as varying from broad to limited and include theories, laws, principles, models, and hypotheses as examples (NRC, 1996). In the case of a specific investigation and the development of a hypothesis, a type of scientific explanation, an explanation is often causal attempting to use evidence and logic to show the relationships between variables in the investigation (NRC, 1996).

A Framework (NRC, 2012), which provides a general framework for the NGSS, and the NGSS (NRC, 2013) both have a very similar view of scientific explanations as the NSES (NRC, 1996), describing scientific explanations as providing an explanation of natural phenomena by linking existing scientific theories with observations that often “explain observed relationships between variables and describe the mechanisms that support cause and effect inferences” using scientific evidence (NRC, 2012, p. 67). A Framework and NGSS discuss the construction of scientific explanations as an important practice to help students understand how major ideas of scientific knowledge are gained and developed through the support of multiples lines of empirical evidence (NRC, 2012, 2013).

Scientific Argument

Science for All Americans (AAAS, 1989) describe scientific arguments as the use logic and reasoning to connect to evidence and any assumptions with the conclusions drawn, which are often scientific claims and/or scientific explanations. These scientific arguments require “true statements and valid connections among them” (AAAS, 1989, p.130). The validity of the connections is based on logic, and the validity of the
statements, or scientific claims, is based on the evidence that supports the statement. This evidence can be collected though observations, collecting, probing, or experimenting that allow for recording measurements using human senses or instruments to enhance human senses or detect properties humans cannot sense (AAAS, 1989). Because evidence and logic are used to validate the scientific claims of an argument, it is important to understand the conditions under which evidence is gathered. A variable can be controlled in attempts to observe and gather evidence on a single condition, this is especially important when trying to determine a causal relationship. However, it is not always possible or moral to control a variable, in which case, a wide range of observations can be used to attempt to understand the variable. To prove logically, through scientific argument, that a scientific claim is true requires examining every possible instance of the claim, which is difficult if not impossible. Therefore, it is much easier to prove a scientific claim is not true, by finding evidence that refutes the claim (AAAS, 1989).

NSEs (NRC, 1996), A Framework (NRC, 2012), and NGSS (NRC, 2013) are very similar to Science for All Americans (AAAS, 1989) in their descriptions of scientific argument. However, the NRC documents focus on science leaning, inquiry, and practices in their descriptions on scientific argument. Scientific arguments allow for alternative explanations or claims to be analyzed and the best explanation to be selected using scientific knowledge, weighing the evidence or data gathered from investigations, and examining logical connections that show how the data support a claim; when weighing evidence, the methods and procedures used to collect the evidence must be considered in its validity in supporting an explanation or claim (NRC, 1996, 2012, 2013). A
Framework (NRC, 2012) and the NGSS (NRC, 2013) address the important practice of students engaging in scientific argument to help them understand the advancement of scientific knowledge through the practice of scientific argument and using reasoning and evidence to support a “new idea or explanation of natural phenomena, the construct, defend their interpretations of the associated data, and advocate for the designs they propose” (NRC, 2012, p.71) all of which have the potential to advance scientific knowledge in a field.

The Relationship between Scientific Explanation and Scientific Argument

Scientific explanation and scientific argument are very closely related scientific inquiry practices. Both have been included in the NSES (NRC, 1996), A Framework (NRC, 2012), and NGSS (NRC, 2013) as either science process skills or practices important in increasing student understanding in science, the process of science, and construction of scientific knowledge. The descriptions the NSES give for scientific explanation and scientific argument are so dependent on each other that it is difficult if not impossible to explain one without the other.

Though they are closely related aspects of science inquiry, scientific explanation and scientific argument are different processes or practices. Scientific explanations are the products of science meant to explain natural phenomena. Scientific arguments develop and justify scientific explanations through the use of reasoning and evidence (Berland & Reiser, 2009; Krajcik, 2012; Osborne & Patterson, 2011). Osborne and Patterson (2011), discuss the importance of consistency when using the terms explanation and argument in the science education literature suggesting that it will help to further the field and understanding of explanation and argument if there is a clear distinction. An
explanation uses evidence that explains, or may provide a causal account of a natural
phenomenon, and an argument logically validates that the evidence are consistent with
the given explanation. If there are multiple explanations for the same natural
phenomenon, scientific argument is meant to persuade that a given explanation is most
inclusive of available evidence and most logically explains available evidence (Osborne
& Patterson, 2011). Additionally arguments are tentative, because they attempt to justify
a claim or explanation given the best available evidence, since it is practically impossible
to examine every instance of a claim, the claim cannot be proven true; if it were proven
true there would be no need for an argument (Osborne & Patterson, 2011).

The Relationship between Scientific Content Knowledge and Scientific Explanation
and Scientific Argument

Scientific content knowledge interacts with a student’s ability to construct
scientific explanation and scientific argument. If a student has difficulty understanding
the content knowledge, he or she will have a difficult time constructing scientific
explanation and argument (Metz, 2000; Sadler, 2004), because construction of scientific
explanations and argument require both knowledge of scientific explanation and
argument as well as relevant content knowledge (McNeill & Krajcik, 2009; McNeill,
Lizotte, Krajcik, & Marx, 2006). McNeill et al. (2006) found that middle school students
scored higher on substance/property items than chemical reaction items on the multiple
choice portion of a posttest and produced better scientific explanations for
substance/property items than chemical reaction items on the same posttest following a
chemistry unit. Difficulty constructing scientific explanations and scientific arguments
may arise, because students must use specific content knowledge as they are selecting
evidence that will support a claim and articulating how the evidence supports the claim (Osborne, Erduran, & Simon, 2004).

Learning involving the construction of scientific explanation and scientific argument influences student content knowledge, and can increase student understanding of content knowledge, possibly more than traditional classroom learning (McNeill & Krajcik, 2009). Middle school students who constructed explanations using the claim, evidence, and reasoning framework for scientific explanation [CER Framework] during a chemistry unit have shown increased content learning and increased ability to apply those concepts to construction of scientific explanations (McNeill et al., 2006), especially when provided with context-specific scaffolds (McNeill & Krajcik, 2009). When students have the opportunity to write explanations and arguments, they have an opportunity to socially and individually construct meanings of the content being explained or argued (McNeill, 2009). Berland and Reiser (2009) suggest that meaning is constructed as students are providing reasoning and connections between evidence and claims during the process of constructing scientific explanations using the CER Framework. Scientific argumentation of human genetics dilemmas and properties of light also had an influence on science content knowledge gained by students. High school biology students scored higher on a genetics-content knowledge assessment when they learned genetics through scientific argumentation of human genetics dilemmas compared to students who learned genetics through a more traditional approach (Zohar and Nemet, 2002). Middle school students who engaged in scientific argumentation using SenseMaker software had increased conceptual understanding of the properties of light (Bell & Linn, 2000).
The Relationship between Epistemology, the Nature of Science and Scientific Explanation and Scientific Argument

Epistemology includes beliefs about knowledge and how knowledge is formed or ways of knowing (Davis, 2009). Science epistemology addresses what is scientific knowledge or how is scientific knowledge formed or the nature of science (McNeill & Krajcik, 2008; Sadler, 2004; Sandoval, 2003). Though the nature of science can differ within various disciplines of science and is still debated among scientists, there are aspects of the nature of science that are accepted among scientists. The goal of science is to produce theories that provide causal explanations of natural phenomena. Science relies on empirical evidence and parsimony. Scientific knowledge can be stable, for example theories, when supported by large amounts empirical evidence and have great explanatory power, and can be tentative and subject to change when supported with less empirical evidence. Scientific knowledge construction is influenced by cultural norms, creativity of scientists, and ethical issues (AAAS, 1989, 1993; NRC, 2013; Sadler, 2004; Sandoval, 2003).

Scientists and students have different views on the nature of science. Students tend to view science as a collection of facts about the natural world and view knowledge as more fixed and known with certainty (Nussbaum, Sinatra, & Poliquin, 2008; Sandoval, 2003). Students who view science as unchanging are less likely to participate in science inquiry practices, like construction of scientific explanations and arguments (Nussbaum & Bendixen, 2003), than students who view science and scientific knowledge as constructed, tested, dynamic, and changing (Linn & Songer, 1993; Windschitl & Andre, 1998). These students are also more willing to consider alternative ideas, data, and reasoning to change their understandings of natural phenomena (Weinstock & Cronin,
2003), because a more scientist-aligned view of the nature of science influences understanding of scientific knowledge, which influences use of reasoning related to that knowledge (Sadler, 2004). Middle school students with views of the nature of science more similar to scientists constructed higher quality scientific arguments while exploring the topic of light propagation (Bell & Linn, 2000). Additionally, undergraduate students who view that scientific knowledge is based on evaluation of evidence were more likely to participate in and had a higher quality of argument during online discussion when attempting to answer physics questions. Additionally, these students correctly answered a higher number of questions correctly (Nussbaum et al., 2008).

Student construction of scientific explanation and argument may influence their views on the nature of science (Bell & Linn, 2000). As students learn how to construct scientific explanations and arguments (and therefore scientific knowledge), and teachers provide a rationale for why evidence and reasoning should be included, the inquiry practice is also informing students’ views on the nature of science (McNeill & Krajcik, 2008; Newton, Driver, & Osborne, 1999; Sandoval, 2003). When students are able to produce quality scientific explanations and arguments, it suggests they have an understanding of the explanations and arguments, and therefore the nature of scientific knowledge meant to explain natural phenomena (Sandoval, 2003). Sandoval (2003) found that high school student constructing explanations of natural selection used causal mechanisms to explain data, an understanding of scientific explanations that begins to align with scientists views of the nature of science inquiry and scientific knowledge. Keys, Hand, Prain, & Collins (1999) found that during a study on water quality middle school students who used science writing heuristic (SWH), which discusses the meaning
of data and encourages students to debate how their data supports their knowledge claims, had more complex understandings of the nature of science in a post instruction interview than prior to instruction.

**Difficulty Constructing Scientific Explanation and Scientific Argument**

Though construction of scientific explanation and scientific argument are important practices in science and science education, research has shown these practices are difficult for the majority of children and adults (Driver, Newton, & Osborne, 2000; Kuhn, 1991; Nussbaum & Sinatra, 2003; Nussbaum et al., 2008; Osborne, Erduran, & Simon, 2004; Sadler, 2004). Specifically, children and adults have difficulty articulating and defending a position or claim (Kuhn, 1991; Sadler, 2004), which is required in scientific explanation and scientific argument. Three aspects that are known to cause difficulty with construction of scientific explanation and scientific argument include: evidence, reasoning, and rebuttals.

**Use of evidence in scientific explanation and scientific argument.** Evidence is critical in validating scientific claims (AAAS, 1989), and is therefore a critical component in scientific explanation and scientific argument. Additionally, science learning results from students connecting evidence to scientific claims (Driver et al., 2000). However, students often have difficulty selecting appropriate evidence to support or validate a claim (Sandoval, 2003), especially when presented with both appropriate and inappropriate evidence (McNeill & Krajcik, 2007). Often students and adults will use opinion rather than evidence to support a claim (Kuhn, 1991); possibly because students have difficulty determining what counts as scientific data that can be used as evidence from other forms of information (Sadler, 2004). Though after explicit
instruction, students can potentially understand appropriate evidence and the necessity of providing data for evidence in scientific explanations (Sadler, 2004; Sandoval & Millwood, 2005).

When students construct scientific explanations and arguments they often fail to explicitly state evidence that supports them, using data to construct a claim, but not to validate the claim, perhaps because they do not find it necessary to support the claim (Sandoval, 2003). Student use of explicit evidence depends on what the student views as evidence required to support the scientific explanation and whether or not the student can make sense of the evidence (Sandoval, 2003; Berland & Reiser, 2009). Also, students attempting to persuade other students, who have not seen the evidence, or defend ideas against alternatives from other students, are more likely to explicitly state the evidence that supports their claim (Berland & Reiser, 2009).

Along with difficulty determining what appropriate evidence is and explicitly stating evidence in scientific explanation and argument; students often have difficulty determining what amounts to sufficient evidence, which is not surprising as scientists also often debate what counts as sufficient data (Sandoval, 2003). Often students use only one piece of evidence when multiple pieces available will increase the strength of an explanation or argument (Sandoval & Millwood, 2005). When students have difficulty understanding the data and the content, they are less likely to include sufficient evidence in an explanation or argument (McNeill & Krajcik, 2007; Sandoval, 2003; Sandoval & Millwood, 2005).

When students do not understand data, they are less likely to use it to construct an explanation that may modify their current understanding of a concept (Chinn & Brewer,
Similarly, students are more likely to use data that correlates with their current understanding, than use data that may modify their current understanding (Sandoval & Millwood, 2005). Students find conflicting evidence difficult to process (Sadler, 2004) and often ignore it or manipulate the data so it correlates with their current understanding (Sandoval & Millwood, 2005).

**Use of reasoning in scientific explanation and scientific argument.** Scientific explanations or claims can be validated by providing data and reasoning or backing, which is logically stating how the data count as evidence to support the claim (AAAS, 1989; Tolumin, 1958). When constructing scientific explanations and arguments, reasoning should include scientific principles that help connect data or evidence to the claim (McNeill, 2009; McNeill et al., 2006). Providing reasoning is one of the most challenging tasks of argumentation. Both students and adults have difficulty stating why evidence will support a claim (Bell & Linn, 2000; Kuhn, 1991; Sandoval & Millwood, 2005). In verbal discourse, students will readily make claims, but rarely provide backing to support them (Jiménez-Aleixandre, Rodriguez, & Duschl, 2000). When writing, students also have difficulty providing reasoning for scientific explanations and argument (Lizzote, McNeill, & Krajcik, 2004; McNeill et al., 2003), especially when attempting to incorporate scientific principles they do not fully understand into reasoning (McNeill et al., 2006). Even middle school teachers had the most difficulty providing instruction for students on use of reasoning in scientific explanation and argument, which is perhaps why their students showed the lowest improvement in the reasoning component of written scientific explanations and arguments (McNeill, 2009).
**Use of rebuttals in scientific explanation and scientific argument.** It is important for students not only to make claims and support those claims with evidence and reasoning during construction of scientific explanations and arguments, it is also important for students recognize they can strengthen their scientific explanations and arguments by acknowledging alternative claims or counterarguments and providing a rebuttal through critiques of the use of evidence and reasoning in those counterarguments (McNeill & Pimentel, 2010). Students have difficulty acknowledging alternative explanations for data (Sadler, 2004). This difficulty often means students will not include rebuttal of alternative claims in their scientific explanations and arguments, especially when students they are written and students are involved in verbal discourse with peers who may provide with alternative claims to be rebutted (Berland & McNeill, 2010). Including counterclaims and providing rebuttals is at the higher end of the learning progression for written scientific explanations and rebuttals, because students need practice considering alternative explanations for data (Berland & McNeill, 2010). Perhaps if students saw the goal of science as persuasion and not as finding the correct answer, they would be more likely to consider alternative explanations for data and provide rebuttals for counterarguments (Berland & Reiser, 2009).

**Explicit Instruction and Construction of Scientific Explanation and Scientific Argument**

Explicit instruction in scientific explanation and scientific argument has resulted in increased quality in of these important practices across grade levels and domains of science. High school genetics students with explicit instruction of argumentation skills incorporated into a unit covering human genetics dilemmas produced higher quality arguments that incorporated correct genetics content knowledge than produced by the
students before the explicit instruction (Zohar & Nemet, 2002). Pairs of college students in a physics course exposed to direct instruction about argument produced better arguments through incorporation of evidence and considering alternative claims while answering physics questions (Nussbaum et al., 2008). Explicit instruction of scientific explanation—where teachers defined scientific explanation and its components—during a middle school chemistry unit resulted in students constructing higher quality scientific explanations (Lizotte, McNeill, & Krajcik, 2004; McNeill, 2009).

Explicit instruction is especially beneficial when students initially lack understanding of the procedures and use of a science inquiry practices, like construction of scientific explanation and scientific argument (Fradd & Lee, 1999; Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999), and should instruct students on how to carry out inquiry practices and why the practice is important in science (Kuhn, Black, Keselman, & Kaplan, 2000; McNeill, 2009; McNeill & Krajcik, 2008). McNeill and Krajcik (2008) investigated the effects of four aspects of instruction in construction of scientific explanation and argument on student learning, which was measured by posttest scores determined from fifteen multiple choice questions and four open ended questions where students constructed scientific explanations, during a middle school chemistry unit. These four aspects of instruction in construction of scientific explanation and argument include modeling scientific explanation, making the rationale of scientific explanation explicit, defining scientific explanation, and connecting scientific explanation to everyday explanation. In this study, modeling scientific explanation and connecting scientific explanation to everyday explanations, which do not use science discourse, did not increase student learning of scientific explanations (McNeill & Krajcik, 2008).
Students taught by teachers who explicitly provided rationale behind construction of scientific explanations had higher learning gains, measured, than students whose teachers failed to include the rationale (McNeill & Krajcik, 2008). The teachers’ ability to explicitly define scientific explanation and its three components: claim, evidence, and reasoning (which are fully discussed under the subheading: The claim, evidence and reasoning instructional framework for construction of scientific explanation and scientific argument), influenced student learning of scientific explanation. Teachers who provided definitions that did not align with the recommended curriculum for the chemistry unit and often over simplified construction of scientific explanation and argument had decreased learning (McNeill, 2009). Overall, teachers were most able to define claim and had the most difficulty defining reasoning; reasoning was also the most difficult component for the students during construction of scientific explanations and argument (McNeill & Krajcik, 2008). McNeill and Krajcik (2008) found an interesting relationship between providing rationale for and defining components of scientific explanation. When both rationale and definitions were included, student learning gains increased, possibly because students understand why the components needed to be included when constructing a scientific explanation. However, when definitions were provided without rationale, student learning decreased from pre- to post-test. McNeill and Krajcik (2008) suggest decreased ability to construct scientific explanations may result from students the rote process of plugging in the components, and failing to understand why scientists construct explanations with evidence and reasoning.
Scaffolding and Construction of Scientific Explanations and Scientific Arguments

Scaffolding was first used to describe interactions between an adult and child, where an adult helps a child complete a task the child would not be able to complete without the adult’s knowledge (Wood, Burner, & Ross, 1976). Vygotsky’s (1978) zone of proximal development (ZPD), which is described as the zone between a child’s ability to solve a problem independently and ability to solve a problem with assistance from guidance or tools, has since been tied to scaffolding (as cited in McNeill et al., 2006). To increase student learning and understanding scaffolding should lie within the ZPD, so the child is challenged to learn from the scaffolding, but the task is not so difficult for the child to complete with the scaffolding (Stone, 1993). Therefore, scaffolding should be continuously adjusted or faded to ensure the child continues to be challenged as his or her understanding is increased (Collin, Brown, and Newman, 1989; Wood et al., 1976).

Scaffolding helps students complete challenging tasks independently to increase student understanding, and should fade as that understanding increases (McNeill et al., 2006).

Traditional scaffolding is based on one-on-one interactions, which is difficult if not impossible for a single teacher in a whole class setting where students have different levels of prior knowledge and skill (Stone, 1998). Written or computer software tools can be used as a way to provide scaffolding to a classroom of students with a single teacher, have been shown to increase student learning. ThinkerTools is curriculum designed by White and Fredrieks (2000) that includes written reflection prompts, which continuously guide students to reflect on the inquiry practices as each step is completed. Students who used the written reflection prompts had greater metacognitive understanding of the inquiry practices than students who did not use the written
scaffolding (White & Fredriekson, 2000). Davis (2003) used Knowledge Integration Environment software to present reflection prompts to students and found that generic reflection prompts were more effective than directed prompts to during student reflection, perhaps because generic prompts increased student responsibility in a similar manner to faded scaffolding, which decreases the support of the scaffolding as the student is more capable of completing a given task.

McNeill and colleagues (2006, 2008) investigated the role of written scaffolding on construction of scientific explanation and arguments during a middle school chemistry unit. McNeill et al. (2006) designed scaffolds to support student construction of scientific explanation. These scaffolds provided generic and context-specific support. Generic support focused on the components of scientific explanation including claim, evidence, and reasoning by helping students understand the general framework that should be included when constructing any scientific explanation. Context-specific supports helped students use specific content knowledge when constructing scientific explanations and changed with each activity. One group of students was provided with continuous scaffolding over the chemistry unit, and the second group of students was provided with faded scaffolding that decreased the amount of detail over the chemistry unit. McNeill et al. (2006) found that both continuous and faded written scaffolds increased the quality of scientific explanations after completion of the unit; however, the group provided with faded scaffolds constructed higher quality scientific explanations on the posttest when no written scaffolds were provided. In a later study, McNeill and Krajcik (2009) compared generic and context-specific written scaffolds on student construction of scientific explanation and argument. Context-specific written scaffolds
increased student ability to construct scientific explanation and argument more than
generic written scaffolds, but only when teachers provided generic verbal scaffolds
highlighting the importance of both generic and context-specific scaffolds in student
learning and understanding of scientific explanation and argument (McNeill & Krajcik,
2009).

Written and computer software scaffolding have been shown to increase student
understanding and construction of scientific explanation and argument during biology,
chemistry, and physics topics for middle and high school students. Written prompts for
constructing scientific explanations during a middle school biodiversity unit increased
content understanding and increased skill in tying evidence to claims (Lee & Songer,
2004 as cited in McNeill et al., 2006). Middle school students using SenseMaker,
computer software that helps students build argument by scaffolding the process of
linking evidence with claims, promotes learning and resulted in improved understanding
of light propagation (Bell & Linn, 2000). Pairs of middle school students using
WorkSpace, web-based reflective inquiry scaffolding, were more able than students
working without scaffolding, to use valid evidence to support their explanations of
ecosystem disturbance; this was especially apparent for pairs of students with lower
cognitive ability (Kyza, Constantinou, and Spanoudis, 2011). ExplanationConstructor,
computer software designed with epistemic scaffolds to provide domain specific
guidance for explaining population changes of finches in Galapagos Islands, helped high
school students use specific evidence to support claims when constructing explanations
that provided causal mechanisms that showed an understanding of the theory of natural
selection (Sandoval, 2003; Sandoval & Millwood, 2005). Regardless if scaffolding is
presented as written prompts or computer software, it can have a positive influence on student learning and understanding while constructing scientific explanation and scientific argument.

**The Claim, Evidence and Reasoning Instructional Framework for Construction of Scientific Explanation and Scientific Argument**

In 2006, McNeill, Lizotte, Krajcik, and Marx published an instructional framework for scientific explanations, which was modified after Toulmin’s (1958) model of argumentation. Through their modifications, McNeill et al. (2006) simplified Toulmin’s model of argumentation, which can be difficult for academic researchers to interpret (Van Eemeren et al., 1996), from four components to three components in attempts to provide an instructional framework that middle school science teachers and students could use.

Toulmin’s (1958) model of argumentation includes four components: claim, data, warrant, and backing, while McNeill et al.’s (2006) framework for scientific explanations includes three components: claim, evidence, and reasoning and has be referred to as the Claim, Evidence, and Reasoning Framework for Construction of Scientific Explanations or CER Framework (Krajcik, 2012). In the CER Framework, claim is comparable to Toulmin’s (1958) claim, and is “an assertion or conclusion that answers a question” (McNeill et al., 2006, p. 158). Evidence in the CER Framework is comparable to Toulmin’s data, which is described as “scientific data that supports the claim” (p. 158) and can include data collected by students through experimentation or observation, or can be provided for students through archived data (McNeill et al., 2006). In the CER Framework, reasoning incorporates both warrant and backing in Toulmin’s (1958) model of argumentation, and is described as the “justification of why data count as evidence to
support a claim” (p. 158); this reasoning provides both the logic and scientific principles that work to show how evidence are linked to and support the given claim (McNeill et al., 2006).

Additional, adaptations to McNeill et al.’s (2006) instructional framework were meant to align the framework with the NSES (NRC, 1996). The NSES discuss the importance of students using evidence and logic to develop scientific explanations, hence the development of a framework for scientific explanation based on claim, evidence, and reasoning. However, McNeill et al. (2006) state, “our work is informed by research both on explanation and argumentation” (p. 157). Here it must be noted that McNeill et al. (2006) have used the term “scientific explanation” to refer to components covered by both the ideas of scientific explanation and scientific argument as described above, an issue that Osborne and Patterson (2011) have discussed as causing confusion when communicating research on explanation and argumentation in the field of science education.

Though the CER Framework was initially developed for use with a middle school chemistry unit first presented by McNeill et al. (2003) and later published by McNeill et al. (2004), the CER Framework has since been used in elementary, middle school, and high school classrooms covering topics in biology, chemistry, and physical science (Berland & McNeill, 2010; McNeill, 2009, 2011; McNeill & Krajcik, 2008, 2009; McNeill & Martin, 2011; McNeill & Pimentel, 2010). Constructing arguments across different domains of science require different content knowledge and may use different evidence, but construction of scientific explanation and argument using evidence and reasoning to support and understand claims is a key goal of science education across
domains of science including physics, chemistry, and biology (Driver et al. 2000). Many disciplines including debate, language arts, mathematics, science, and social science value and teach argument and the general structure and cognitive practice of it remains the same, the content and context of the argument is what differs (Kuhn, 1993; McNeill et al., 2006).

**Scientific Explanation and Argument in Undergraduate Courses**

Coordinating claims and evidence through reasoning makes the construction of scientific explanations and arguments difficult undergraduate students and adults (Kuhn, 1991; Stark, 2005; Stark et al., 2009). Little research has investigated the use of explicit instruction in constructing scientific explanations and arguments at the college level, especially introductory biology laboratories. Research on construction of scientific explanations and arguments in education and various science courses are discussed below.

Much of the available research on scientific explanation and argument at the undergraduate level has taken place in education courses, which is reasonable as future science educators should have an understanding of scientific explanation and argument. Explicit instruction in scientific argument in undergraduate education courses improved student ability to construct scientific explanations and arguments covering content across science disciplines. Stark, Thomas, and Krause (2009) investigated the use of an elaboration tool to assist upper-level undergraduate, education students in construction of scientific arguments in a problem-based e-learning environment. Though both students who used the elaboration tool and students without assistance constructed poor argument, students with assistance of the elaboration tool had significantly better arguments (Stark
et al., 2009). Zembal-Saul, Munford, Crawford, Friedrichsen, and Land (2002) investigated the affect *Galapagos Finches* scaffolding software had as preservice science teachers constructed evidence-based arguments about natural selection during a advanced methods course. The preservice science teachers were successful in constructing arguments supported by evidence when using scaffolding software, though the arguments lacked complexity and use of counterarguments and rebuttals (Zembal-Saul et al., 2002). Nussbaum, Sintra, and Poliquin (2008), analyzed the arguments constructed by pairs of students enrolled in undergraduate education courses as they attempted to solve physics problems. Student pairs who received explicit instruction in argumentation not only developed better arguments, they also answered significantly more problems correctly. Nussbaum et al. (2008) also found that students’ epistemic beliefs influenced level of argument and accuracy of answers.

Undergraduate education courses also have students critique scientific knowledge presented in journal articles on socio-scientific issues including therapeutic cloning and environmental issues similar to instruct students in scientific explanation and argument. Jiménez-Aleixandre and Federico-Agraso (2009) had students compare a peer-reviewed scientific journal article written by Hwang et al. (2004) on human somatic cell nuclear transfer and therapeutic cloning to journalist reported versions of the article to better understand how undergraduate science education students view argument structure and the importance of using reasoning to connect evidence to claims. Hwang et al. (2004) article provided evidence for successful somatic cell nuclear transfer, but did not present supporting evidence for the application claim of therapeutic cloning. The journalistic reported versions focused on the application of therapeutic cloning over nuclear transfer,
which was actually supported with evidence. The students’ cited evidence supporting nuclear transfer and therapeutic cloning after reading the journalistic reported version, and often stated they were for this type of research because of the therapeutic cloning applications, even though there was no supporting evidence for therapeutic cloning, suggesting there is a need to discuss argument structure to promote science literacy (Jiménez-Aleixandre and Federico-Agraso, 2009). Environmental education is another socio-scientific issue that provides a platform for construction of scientific explanation and argument. Uskola, Maguregi, and Jiménez-Aleixandre (2010) examined the role of argumentation when groups of students in an environment and informal education course were instructed to choose the best heating system based. Student groups use a variety of criteria to argue their position on the best heating system including: comfort, economic, ecological, pollution, pragmatic, resources, and sustainability. However, no group used all of these criteria, and data contradicting the groups’ choice of heating system were not included. During the activity students developed environmental concepts of sustainability and renewable, the authors suggest that discussion and argumentation promoted a higher level of abstraction of these difficult concepts (Uskola et al., 2010).

Lin, Hong, Wang, and Lee (2011) examined the role of explicit instruction in scientific explanation and argument in a course on the history of science including science majors and non-majors. The authors found that undergraduate students instructed to use Toulmin’s components of argument, data, evidence, warrants, and backing had improved argument ability when trying to persuade fellow students of the correct answers to high school level physics problems in an online discussion. Prior to instruction in argument and online discussion the science majors constructed higher quality arguments
and higher level of physics concept knowledge; after instruction in argument and online discussion there was less of a difference between the science majors and non-majors (Lin et al., 2011).

Research on teaching scientific explanation and argument in an undergraduate biochemistry course recommends critique of scientific knowledge presented in journal articles similar to research done in education courses. Johnson (2011) used peer reviewed journal publications discussing the mechanisms of the ribosomal peptidyl transferase reaction to teach students in an upper-level biochemistry course the importance of claims, evidence, arguments, and counterarguments in science discourse. Students read, discussed, and completed activities using journal articles to learn the importance of critique and argumentation in scientific discourse and the accepted mechanism of the ribosomal peptidyl transferase reaction (Johnson, 2011).

Research has shown instruction with a focus on construction of scientific explanations and arguments in undergraduate chemistry laboratory courses has increased student ability to construct scientific explanations and arguments and chemistry content knowledge. Hand and Choi (2010) examined the use of multiple modal representations (presenting written, symbolic, and graphic data) and the Science Writing Heuristic (SWH) as undergraduate students in an organic chemistry laboratory course constructed written arguments. The SWH is an instructional model that guides students to use the structure of argument (question, claim, evidence, and reflection) when writing a report on laboratory activities. Overall the arguments written using the SWH were of low to moderate quality. However students who were able to include multiple modal representations in their evidence and had a better understanding of the data, produced
higher quality reasoning connecting evidence to the claim, and therefore higher quality of arguments (Hand & Choi, 2010). Students who produced higher quality arguments also earned higher scores on laboratory examinations. Walker, Sampson, Grooms, Anderson, and Zimmerman (2012) examined the effect Argument-Driven Inquiry (ADI) in an introductory chemistry laboratory course. ADI is an instructional model that focuses students to develop an explanation for a research questions and support the explanation with an argument. Students design a method to collect and analyze data, which they then use to construct an explanation. Students then engage in argument to justify, with evidence, their explanations. After argumentation, students produce, present, and critique written laboratory reports (Walker et al., 2012). Students who participated in ADI were constructed higher quality arguments than students in a traditional introductory chemistry laboratory course, ADI students providing more evidence and stronger reasoning to link the evidence to their conclusions (Walker et al., 2012). Though ADI helped students construct higher quality arguments and resulted in a more positive attitude to chemistry, especially for female students, conceptual understanding of content did not differ for students instructed through ADI and the traditional laboratory course (Walker et al., 2012).

These research studies show the positive influence instruction of student instruction in scientific explanations and argument at the undergraduate level including education courses (some covering biology content), a biochemistry course, and chemistry laboratories (Hand & Choi, 2010; Johnson, 2011; Walker et al., 2012), but not in biology laboratories. Though use of instruction in scientific explanation and argument during biology learning has been researched in middle, and high school classes, there is a lack of
research showing how explicit instruction in scientific explanation and argument affect students in undergraduate biology courses. This research study will investigate the effect of CER Framework (McNeill et al., 2006) in an undergraduate introductory biology laboratory course in the Southeastern United States.
CHAPTER 3.
METHODOLOGY

Population and Sample

The target population for this study was defined as students enrolled in an undergraduate introductory biology laboratory course at a regional university in the southeastern United States, which is categorized as a Southern Regional Educational Board (SREB) Four-Year Institution, as a Carnegie Master’s College and University I, and as a Southern Association of Colleges and Schools (SACS) and Commission on Colleges (COC) Level V institution. For the purpose of this study, an undergraduate introductory biology laboratory course was defined as a course that meets for two hours of laboratory exercises a week for studying the principles of biology from the cellular level including biochemistry, cell biology, molecular biology, and genetics.

Ninety-six students enrolled in four sections of undergraduate introductory biology laboratory, instructed by the researcher and involved in this study, were the sample population. Students enrolled separately in introductory biology laboratory and lecture courses. Students may have had prior credit for the lecture course, were concurrently enrolled in the lecture course, or may not have taken the lecture course. The sample population included all students in the sample who agreed to participate when requested to do so and completed necessary assessments. Descriptive statistics of the population sample are included in the Results section. Two instructional methods (explicit instruction in scientific explanation and argument in biology laboratories and traditionally-designed biology laboratories) were randomly assigned to two sections each. There were 40 students in the experimental group and 39 students in the control group who completed the necessary assessments through out the course of the study. The
Quasi-Experimental Design

The study used a quasi-experimental research design (Cook & Campbell, 1979, 1986), because participants were not be randomly assigned to the experimental group and the control group. Instead, participants enrolled in introductory biology laboratory and two sections were randomly selected using a random number table to be the experimental group and the other two sections taught by the same instructor were the control group. A nonequivalent comparison-group design was used to compare pretests and posttests of students with explicit instruction in scientific explanation and argument and with students taking traditionally-designed biology laboratories (Cook & Campbell, 1979, 1986). When using a quasi-experimental design, there can be threats to the internal validity of the study, or the ability to infer that a causal relationship exists between two variables, because it is not possible to rule out the influence of confounding variables or variables other than the independent variables that affect the dependent variables, and the validity of the conclusions. However, randomly assigning sections to the experimental group or the control group and not letting participants self-select their groups and by reducing pretest differences between the experimental group and the control group can help to produce unbiased results (Johnson & Christensen, 2012). Matching the experimental group and control group on variables correlated with the dependent variable can reduce pretest differences. However, since this was not possible, posttest scores were
statistically adjusted for pretest differences and other demographic and academic history variables correlated with the dependent variable (Cook & Campbell, 1979, 1986; Johnson & Christensen, 2012).

**Variables**

The independent variable was the instructional method. The first dependent variable was student ability to construct a written scientific explanation and support it with a scientific argument assessed using a rubric designed by the researcher (see Appendix 1). Written scientific explanation and argument were directly assessed through pretest and posttest items providing students with a scenario and data collected, and students were asked to construct a scientific explanation and argument. The second dependent variable was biological content knowledge including biochemistry, cell biology, molecular biology, and genetics, which was directly assessed using the department introductory biology lecture course exam modified to cover laboratory material as a pretest and the average of the midterm and final introductory biology laboratory course exams for the course as a posttest (see Appendix 2). The content of the pretest and posttest was checked for content validity by an expert, the introductory biology laboratory coordinator at the university where the study took place, as Zohar and Nemet (2002) used an expert to check content validity of the multiple choice exam that was slightly modified from past semester matriculation exams used to assess students’ genetic knowledge. The third dependent variable was the score on a formal written laboratory report assessed using a rubric (see Appendix 3). The fourth dependent variable was student perception of biology as a discipline of science, which was assessed by the Colorado Learning Attitudes about Science Survey for Use in Biology (CLASS-
bio) (Semsar, Knight, Birol, & Smith, 2011) (see Appendix 4). Student self-reported demographic and academic history data was used to describe the sample population and as additional dependent variables. A survey modified from the demographic portion of CLASS-bio (Semsar et al., 2011) was used to learn demographics and academic history, including science course history, of students (see Appendix 5).

**Instrumentation**

The researcher collected data from participants over the course of the Fall 2013. Rubrics and the Colorado Learning Attitudes about Science Survey for Use in Biology (CLASS-bio) were two instruments that were used during data collection. Data collection included open-ended written responses in the form of written scientific explanations and arguments and formal written lab reports. Rubrics, which are especially useful when assessing open-ended written responses, were used. Student perception of biology as a discipline of science was assessed using the CLASS-bio. These two instruments are discussed in length below.

**Rubrics**

The researcher used rubrics to assess student ability to construct a written scientific explanation and support it with a scientific argument and a formal written lab report. Rubrics have many advantages for assessment of open-ended written responses. Rubrics promote more consistent assessment from one written response to the next (Stevens & Levi, 2005), which was critical in this research, as the researcher compared the quality of written scientific explanation and argument over time for approximately 96 students. By establishing performance anchors for an assignment and presenting them in a rubric, the instructor/researcher and students/participants were aware of expectations
for the highest and lowest levels of work for a given assignment. This provided students with explicit information on what was expected from them. Additionally, when instructors have an idea of the various levels of work, they can grade assignments more quickly and consistently (Stevens & Levi, 2005). For the instructor/researcher, perhaps the ability to provide detailed feedback in an efficient manner was the greatest advantage of rubrics. Often students make similar mistakes, so instructors are writing the same notes over again from one student to the next. A detailed rubric describing what is required for low to high quality, allows the instructor/researcher to reference these descriptions and provide more detailed feedback to students in a short amount of time (Stevens & Levi, 2005). The strength, reliability, and validity of a rubric are developed through the use of the rubric, which allows the assessor to discover limitations and make revisions (Stevens & Levi, 2005).

To assess student ability to construct a written scientific explanation and support it with a scientific argument, the researcher modified a base rubric for scientific explanation and argument developed by McNeill, Lizotte, Krajcik, and Marx (2006) (see Appendix 1) by making it appropriate for use in an undergraduate introductory biology course. A base rubric is a general description of what is expected from students for each component of scientific explanation and argument. One major modification of McNeill et al. (2006) rubric was the inclusion of counter arguments and rebuttals in the rubric, which may be too difficult for elementary and middle school students and is at the higher end of the learning progression for construction of scientific explanations and argument (Berland & McNeill, 2010; McNeill & Martin, 2011). Additionally in order for college level students to meet the highest quality level when making a claim, students must not
only answer the question being addressed in the activity or experiment, they must also show a causal relationship between the independent and dependent variables. The ability to make a claim that states a causal relationship between variables is also highest on the learning progression for construction of scientific explanations and arguments (Berland & McNeill, 2010). Specific rubrics to fit content for the pretest, each of the four laboratory activities or experiments, and the posttest were developed by the researcher as recommended by McNeill et al. (2006) (see Appendices 6-12).

Students’ formal written lab reports were also assessed using a rubric (see Appendix 3). This rubric, provided by the introductory biology laboratory coordinator, is used by all instructors who teach introductory biology laboratory courses at Southeastern Louisiana University.

**Colorado Learning Attitudes about Science Survey for use in Biology Courses**

The Colorado Learning Attitudes about Science Survey (CLASS) was first developed for use in physics courses, but has since been modified for use in chemistry and biology courses. CLASS-Phys, -Chem, and -Bio assess student perceptions of science on a continuum of novice-to-expert level in three main areas: (a) the content and structure of knowledge, (b) the source of knowledge, and (c) problem solving approaches. Novices view content and structure of science knowledge as isolated, while experts view knowledge as structured around a framework of concepts. Novices view knowledge as originating from a source of authority and not connected with the real world, while experts view knowledge about the world gained through experiments attempting to understand nature. Novices often used memorized patterns to attempt to solve problems, while experts use concept-based approaches applicable to multiple
problems to be solved (Semsar et al., 2011). CLASS-Bio was designed for use in a variety of undergraduate biology courses including majors and nonmajors courses and lower- and upper-level courses. CLASS-Bio is an epistemological assessment with thirty-two items on a five-point scale ranging from strongly disagrees to strongly agrees, the midpoint is neutral. CLASS-Bio reliability was tested by calculating a test-retest coefficient of stability on student responses from two equivalent populations \((n > 600)\), which measures stability over time rather than internal consistency (as measured by Cronbach’s alpha) and can be used on the multiple constructs of CLASS-Bio rather than a single construct for which Cronbach’s alpha was designed. A coefficient for stability of \(r = 0.80\) is considered highly reliable, and the CLASS-Bio coefficients of stability for percent-favorable responses is \(r = 0.97\), percent neutral responses is \(r = 0.91\), and percent unfavorable responses is \(r = 0.97\) (Semsar et al., 2011). Validity of CLASS-Bio was measured using concurrent validity, in which the scores of biology majors and non-biology majors, or populations with expected differences, were tested. The biology majors consistently scored significantly higher scores on CLASS-Bio (Semsar, et al., 2011).

Before scoring students’ pretests and posttests, student responses that took fewer than three minutes and did not select agree for Question 28, which states “We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers” were discarded, because these students most likely did not take completion of the instrument seriously (Semsar et al. 2011). To score students’ CLASS-Bio pretests and posttests, the five point Likert scale: (a) strongly disagree, (b) disagree, (c) neutral, (d) agree, and (e) strongly
agree are condensed to a three point Likert scale: (a) disagree, (b) neutral, and (c) agree, because differences between “strongly disagree” and “disagree” and “strongly agree” and “agree” are not necessarily equal from student to student (Semsar et al., 2011). Student responses were then designated as being favorable, neutral, or unfavorable. Responses that are designated favorable are aligned with expert views of a statement, regardless if the expert view is agree or disagree for a particular statement. A percentage favorable score was then calculated for each student describing the number of statements to which the student had an identical response as the expert consensus (Semsar et al., 2011).

**Data Collection**

Data collection occurred over the course of the Fall 2013 semester during which the introductory biology laboratory class met 14 times for a two hour class meeting. At the beginning of the first class meeting, students were told of the study and told their participation was not mandatory nor would their participation or lack of participation affect their final grade. Students were informed that all information would be kept confidential. After completion of the consent form (see Appendix 19), students completed the Colorado Learning Attitudes about Science Survey for Use in Biology (CLASS-Bio) (Semsar et al., 2011) (see Appendix 4) followed by a brief demographics and academic history survey (see Appendix 5). Students then completed a pretest that included test items on biological content knowledge including biochemistry, cell biology, molecular biology, and genetics, and a scenario from which students will be asked to construct a written scientific explanation and argument (see Appendix 2). After completion of the consent form, surveys, and pretest, the first laboratory class meeting followed.
Written scientific explanations were collected from the experimental group after completion of activities and experiments from Weeks 1, 2, 6, and 9. Written null and alternative hypotheses, which students reject or fail to reject and why were collected from the control group after completion of activities and experiments from Weeks 1, 2, 6, and 9. Written lab reports were collected from the experimental and control groups after experiment from Week 9 was completed.

At the time of the final laboratory class meeting, students took a Final Exam. This score was averaged with the score from the Midterm Exam, given Week 7, to give each student a posttest score for biological content knowledge. After completion of the Final Exam, students completed CLASS-Bio as a posttest (Semsar et al., 2011) (see Appendix 4). Data collection is summarized in Table 3.1 below.

Table 3.1. The timeline for data collection during the 14 week undergraduate introductory biology laboratory course.

<table>
<thead>
<tr>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 9</th>
<th>Week 10</th>
<th>Week 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Termite Activity</td>
<td>Goldfish Cellular Respiration Experiment</td>
<td>Diffusion &amp; Osmosis Experiment</td>
<td>Photosynthesis Experiment</td>
<td>Photosynthesis Experiment Written Lab Report</td>
<td>Final Exam Posttest</td>
<td>CLASS-Bio Posttest</td>
</tr>
</tbody>
</table>

The Experimental and Control Treatments

During one semester of the undergraduate introductory biology laboratory course, there are three experiments in which students collected quantitative data including two
experiments covering metabolic pathways (cellular respiration and photosynthesis) and one experiment covering diffusion and osmosis. On the first day of class, students in the experimental group, were introduced to science as a way of knowing about the world through observation and evidence and received explicit instruction on scientific explanation and argument through a modified claim, evidence, and reasoning framework (McNeill, Lizotte, Krajcik, & Marx, 2006). Students were given a copy of the modified McNeill et al. (2006) claim, evidence and reasoning base rubric (see Appendix 1). Each laboratory meeting began with introducing the activity topic and additional explicit instruction on scientific explanation and argument, and traditionally designed laboratories used as described in the laboratory manual (White and Campo, 2013); however students focused on constructing written scientific explanations and supporting them with scientific argument during the termite activity and the three experiments where students collect quantitative data. The students’ written explanations and arguments were collected for assessment by rubric after the termite activity and the three experiments where students collect quantitative data. In the control group, on the first day of class students were introduced to science through the scientific method and experimental design, each laboratory meeting began with a brief introduction on the activity topic, traditionally designed laboratories will be used as described in the laboratory manual (White & Campo, 2013) where students focused on rejecting or failing to reject written hypotheses and explaining why during the termite activity and the three experiments where students collect quantitative data. What follows is an overview of each of the lesson plans for the experimental and control laboratory sections.
Termite Activity: Week 1

During the Week 1 laboratory activity, students were first introduced to science and biology. Then students completed an activity that allowed them to apply what they learned about science, the scientific method, and experimental design by investigating the movement of termites around circles drawn with ink.

**Experimental group.** Students were introduced to science as a way of knowing about the world through observation and evidence and received explicit instruction on scientific explanation (which includes null and alternative hypotheses) and argument (which includes experimental, as well as, how to obtain appropriate and sufficient evidence) through a college level appropriate, modified claim, evidence, and reasoning framework (McNeill et al., 2006). Students completed the termite activity during which students practiced writing null and alternative hypotheses with independent and dependent variables and using the CER Framework to construct written scientific explanations and argument using qualitative data from termite activity to answer the question: “Why do termites follow the blue Papermate® ink circle?” (see Appendix 13).

**Control group.** Students were introduced to science through the scientific method and experimental design, which includes the ideas: independent variable, dependent variable, control, null hypothesis, and alternative hypotheses. Students completed the termite activity, during which students practice writing null and alternative hypotheses with independent and dependent variables and discussing why they think the termite behaved in the observed manner (following the blue Papermate® ink circle) (see Appendix 13).
Goldfish Cellular Respiration Experiment: Week 2.

Students were introduced to respiration (breathing) and cellular respiration (aerobic respiration or metabolism in which cells produce energy) and how the two processes are connected, as well as, how animals regulate body temperature (ectotherms and endotherms). Students applied knowledge of the scientific method and experimental design by completing an experiment that investigated the effect of decreasing water temperature on goldfish breathing rates.

Experimental group. Students were reminded that science is a way of knowing about the world through observation and evidence. Students reviewed college level appropriate, modified claim, evidence, and reasoning framework (McNeill et al., 2006) for constructing scientific explanations and arguments with a focus on obtaining appropriate and sufficient evidence in the form of quantitative data. Students conducted the goldfish cellular respiration experiment during which, students practice writing null and alternative hypotheses with independent and dependent variables and using the claim, evidence, and reasoning framework to construct written scientific explanations and argument using quantitative data from goldfish cellular respiration experiment to answer the question: “How does water temperature affect goldfish respiration?” (see Appendix 14).

Control group. Students were reminded of the scientific method and experimental design. Students conducted the goldfish cellular respiration experiment, during which students practiced writing null and alternative hypotheses with independent and dependent variables. Students rejected or failed to reject their hypotheses discussing how water temperature affects goldfish respiration (see Appendix 14).
Diffusion and Osmosis Experiment: Week 6

Students were introduced to diffusion and osmosis, as well as factors contributing to the rate of diffusion and osmosis including the ideas: Brownian motion, concentration gradient, equilibrium, selectively permeable membranes, isotonic environments, hypotonic environments, and hypertonic environments. Students applied knowledge of the scientific method and experimental design by completing an experiment that investigates the effect of concentration gradient on the rate of diffusion when dialysis tubing “cells” were placed in isotonic, hypotonic, and hypertonic environments.

Experimental group. Students were reminded that science as a way of knowing about the world through observation and evidence. Students reviewed college level appropriate, modified claim, evidence, and reasoning framework (McNeill et al., 2006) for constructing scientific explanations and arguments with a focus on obtaining appropriate and sufficient evidence in the form of quantitative data. Students conducted the diffusion and osmosis experiment during which, students practiced writing null and alternative hypotheses with independent and dependent variables and using the claim, evidence, and reasoning framework to construct written scientific explanations and argument supported by appropriate and sufficient quantitative data and including an alternative claim/argument that is refuted using appropriate and sufficient quantitative data from diffusion and osmosis experiment to answer the questions: “Why do cells change weight at different rates?” (see Appendix 15)

Control group. Students were reminded of the scientific method and experimental design. Students conducted the diffusion and osmosis experiment, during which students practice writing null and alternative hypotheses with independent and
dependent variables. Students rejected or failed to reject their hypotheses discussing why the cells are changing weight at different rates. (see Appendix 15).

**Photosynthesis Experiment: Week 9**

Students were introduced to the process of photosynthesis. First, autotrophic organisms were introduced as being able to carry out photosynthesis and examples including plants, algae, some protists, and some bacteria are given. The remainder of the introduction focused on photosynthesis in green plants. The overall reaction of photosynthesis and the overall reaction of cellular respiration were compared. Next, the two main steps of photosynthesis: light dependent reactions and light independent reactions were discussed. Then, the overall reaction was used to discuss what can be measured as a dependent variable to estimate the rate of photosynthesis occurring. Students apply knowledge of the scientific method and experimental design by completing an experiment that investigates the effect of light intensity on the rate of photosynthesis.

**Experimental group.** Students were reminded that science as a way of knowing about the world through observation and evidence. Students review college level appropriate, modified claim, evidence, and reasoning framework (McNeill et al., 2006) for constructing scientific explanations and arguments with a focus on obtaining appropriate and sufficient evidence in the form of quantitative data and the idea of alternative claims/arguments and how refuting an alternative claim/argument using evidence and reasoning can strengthen a scientific explanation and argument. Students conducted the photosynthesis experiment, during which students practiced writing null and alternative hypotheses with independent and dependent variables and using the claim,
evidence, and reasoning framework to construct written scientific explanations and argument supported by appropriate and sufficient quantitative data and include an alternative claim/argument that was refuted using appropriate and sufficient quantitative data from diffusion and osmosis experiment to answer the questions: “How does light influence photosynthesis?” (see Appendix 16). Students wrote a formal lab report on the photosynthesis experiment.

**Control Group.** Students were reminded of the scientific method and experimental design. Students conducted the photosynthesis experiment, during which students practiced writing null and alternative hypotheses with independent and dependent variables and discussing the importance of light in the process of photosynthesis (see Appendix 16). Students wrote a formal lab report on the photosynthesis experiment.

**Data Analysis**

Data collected in this study was analyzed using IBM SPSS for Windows (Version 20.0). First, descriptive statistics for the sample population were run including age, gender, race, year in school, and major. Data was then analyzed to address the three main objectives of this research study as discussed below.

**Objective 1**

The first objective of this research study was to compare students receiving the experimental treatment who are explicitly instructed in scientific explanation and argument and a control group of students instructed through traditionally-designed biology laboratories. This objective was broken down into the following questions and hypotheses:
(a) Will explicit instruction in scientific explanation and argumentation improve student ability to write scientific explanations and arguments, over students instructed through traditionally-designed laboratories?

$H_0$: The treatment will not affect ability to write scientific explanations and arguments.

$H_A$: The treatment will improve ability to write scientific explanations and arguments.

(b) Will explicit instruction in scientific explanation and argumentation improve student biological content knowledge, over students instructed through traditionally-designed laboratories?

$H_0$: The treatment will not affect biological content knowledge.

$H_A$: The treatment will increase biological content knowledge.

(c) Will explicit instruction in scientific explanation and argumentation improve student ability to write a formal laboratory report, over students instructed through traditionally-designed laboratories?

$H_0$: The treatment will not affect ability to write formal lab reports.

$H_A$: The treatment will improve ability to write formal lab reports.

(d) Will explicit instruction in scientific explanation and argumentation influence students perception of biology as a discipline of science, over students instructed through traditionally-designed laboratories?

$H_0$: The treatment will not affect students’ perception of biology as a discipline of science.
Hₐ: The treatment will affect students’ perception of biology as a discipline of science.

Due to the quasi-experimental design of this research study based on intact groups of subjects being used as the sample population, an analysis of covariance (ANCOVA) was used to test these hypotheses (Cook and Campbell, 1979, 1986). With ANCOVA, a researcher can explain variation of the dependent variables through statistical control of extraneous variables, which are treated as covariates. When using nonequivalent comparison-group design to compare pretest and posttest scores, the pretest scores were used as the covariate to adjust for initial differences between the experimental and control groups (Cook & Campbell, 1979, 1986). Considering differences in the experimental and control groups was important; therefore ANCOVA should only be used if initial differences are small between the groups on the covariate. Descriptive statistics of the dependent variables and covariates were included for each hypothesis tested. Before testing each hypothesis, assumptions for ANCOVA were tested. The covariate was linearly related to the dependent variable and showed homogeneity of the regression slopes, meaning the covariate had no interaction with the treatment. Samples were independently collected; in this study the experimental and control groups were composed of different students and therefore are independent. The dependent variable had a normal distribution, which was tested using the Shapiro-Wilk test. In the case that the assumption of normality was not met, the ANCOVA was conducted anyway as the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al 2003, p 345). In addition to a normal distribution of the dependent variable, the conditional distributions were checked for normality and the standard deviations of each
The distribution was equal as shown by an equal distribution of standardized residuals over predicted values for the dependent variable, meeting the assumption of homoscedasticity. The homogeneity of variance, or that the variances of the distributions in the populations are equal, which was tested by Levene’s F. After testing the appropriate assumptions, ANCOVA was used to test each of the four hypotheses listed above.

**Objective 2**

The second objective of this research study was to evaluate student progress of ability to write scientific explanations and arguments over the course of the semester. Students receiving explicit instruction in scientific explanation and argumentation wrote six explanations and arguments over the course of the semester. These explanations and arguments were evaluated to address the following question and hypothesis:

Will students’ ability to write scientific explanations and argument continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Posttest)?

H₀: Student ability to write scientific explanations and arguments will not change over the course of the semester [from Pretest to Week 1, 2, 6, 9 to Final Exam].

H₁: Student ability to write scientific explanations and arguments will change and perhaps increase over the course of the semester [from Pretest to Week 1, 2, 6, 9 to Final Exam].

Repeated measures one-way analysis of variance (ANOVA) allows measuring an individual multiple times on the dependent variable, which in this study was written scientific explanations and arguments assessed by rubric. Scores from the same individual were dependent samples, while scores from different individuals were independent samples. Using repeated measures one-way ANOVA, with time as the
repeated factor, allowed the researcher to see if there were significant changes in
students’ ability to write scientific explanations and argument continuously increase
during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)
(McNeill et al., 2006). When conducting repeated measures ANOVA, it is important to
determine the F distribution is appropriate to test the null hypotheses and the following
assumptions must be met. First, for each time the dependent variable was collected the
data was assessed for outliers by checking for existing cases with standardized residuals
greater than ±standard deviations. The dependent variable had a normal distribution,
which was tested using the Shapiro-Wilk’s test. However, the effect of violating the
assumption of normality on Type I error rate is minimal (Hinkle et al, 2003, p 345), so if
this assumption is violated the repeated measures ANOVA was still completed.
Repeated measures ANOVA requires compound symmetry, meaning not only must
population variance be equal, but population covariance must also be equal. Compound
symmetry can be established using Mauchly’s test for sphericity. If the assumption of
sphericity is violated, the Type I error rate can be affected. A correction to the degrees of
freedom can provide a conservative $F$ value and statistical test for the null hypothesis, to
compensate for the Type I error rate by lowering it (Hinkle et al, 2003, p. 361).
Greenhouse-Geisser was used to correct the degrees of freedom when epsilon, which
measures the violation of sphericity, was close to or less than 0.75 (Girden, 1992). After
testing the appropriate assumptions, repeated measures ANOVA was used to test the
hypothesis listed above addressing written scientific explanations and arguments as a
whole. If the null hypothesis was rejected, post hoc analysis with Bonferroni correction
was used to determine where there were statistically significant differences between the
scientific explanations and arguments collected over the course of the semester.
Repeated measures ANOVA was also used to investigate student progress of ability to
write the four components of scientific explanations and arguments, which include claim,
evidence, reasoning, and counter argument, over the duration of the semester.

**Objective 3**

The third objective was to understand how various demographic and academic
variables can influence student ability to construct written scientific explanations and
arguments. This objective will answer the following question: What demographic and
academic variables positively influence student ability to construct scientific explanations
and arguments?

Standard multiple regression with significance set at $p = 0.05$ was used to
investigate this question. A standard multiple regression analysis requires the
assumptions of independent samples, a normal distribution of the dependent variable for
each influencing variable, which was tested by comparing measures of central tendency
as well as looking at a histogram of the standardized residuals, no outliers in the data,
which was tested by assessing for existing cases where standardized residuals are greater
than $\pm 3$ standard deviations, a linear relationship between the dependent variable and
each influencing variable, which was tested by observing scatter plots, and no collinearity
between influencing variables, which was tested by looking at a correlation table of all
variables and tolerance values. If two influencing variables have an $R^2$ value above 0.3,
where $R^2$ is the proportion of variance explained by the other variable, one of the
influencing variables should be removed. Tolerance values smaller than 0.1 suggest that
the assumption of collinearity has been violated.
When using standard multiple regression, the final model is tested for statistical significance based on the correlation coefficients and $R^2$ values of each influencing variable. The model predicts also reports which variables are most influential on student ability to construct scientific explanations and arguments and are statistically significant in the overall model.

**Reliability, Validity, and Biases**

When conducting research reliability, validity, and biases are critical aspects to address. In quantitative research, reliability is measured by the consistency and stability of the results in a research study. Reliability of research can be demonstrated by obtaining similar results during replications of the research. The validity of the research refers to the correctness of the inferences made from the data. There are a number of different aspects of validity to consider in a quantitative research study. Internal validity is the ability to infer a causal relationship between two variables. As discussed above, the quasi-experimental design can threaten the internal validity of this research, which can be addressed by randomly assigning sections to the experimental group or the control group and statistically adjusted posttest scores. External validity refers to the ability of the results to be generalized across populations, times, and settings. The target population for this study includes students enrolled in undergraduate introductory biology laboratory courses during the Fall 2013 semester at the regional university where the study took place. Therefore results from this study can be generalized to all students in undergraduate introductory biology laboratory courses. The reliability and validity of instrumentation must also be considered and is discussed above (see Variables and Instrumentation).
Because this is a quantitative study, statistical analyses will be used to validate inferences about relationships between two variables. Whether or not there is a relationship was tested, and the strength of the relationship was determined. Effect size will be calculated to determine the strength of the relationship between variables. In educational research significance levels are normally set to $\alpha = 0.05$, therefore the type I error rate that a true null hypothesis will be incorrectly rejected is 5%. Type II error rate ($\beta$) is the chance that a false null hypothesis is not rejected. The power of a statistical test is the ability to reject a false null hypothesis ($1 - \beta$). The power of a statistical test is affected by the level of significance, the sample size, and the effect size (Hinkle et al., 2003).

Though quantitative research can be characterized as being objective, it is still important to recognize the role of the instructor, the researcher, and resulting biases when conducting educational research. I have both a Bachelor of Science and a Master of Science in biology. I believe my strong science background has led me to quantitative research. My enjoyment of teaching biology inspired me to pursue a Doctoral degree in science education. My experience taking education courses has influenced my instruction and understanding of learning in the classroom. For this research study, the researcher was also the instructor. Instructors typically play a critical role in instruction of scientific explanation and argument (McNeill and Krajcik, 2008), and a future instructor who does not show the same level of enthusiasm, commitment to science education, or this research study may not obtain similar results.
CHAPTER 4.
RESULTS

Of the 96 students initially enrolled in one of four sections of an undergraduate introductory biology laboratory course selected for the sample population of this study, 79 of those students participated in the study; however all not all participants completed all assessments. Of the 79 students who participated in the survey, 40 were in the experimental group, and 39 were in the control group. The age of the participants ranges from 18 to 49, with a mean age of 19.80 ± 4.22; the experimental group mean age was 20.53 ± 5.11 and the control group mean age was 19.46 ± 3.09 (Figure 4.1). The overall sample population was 65.8% female and 34.2% male. The experimental group was 67.5% female and 32.5% male, while the control group was 64% female and 36% male (Figure 4.2). The overall sample population was 72% White, 19% African American, 1.3% Native American, 3.8% Asian, and 3.8% Hispanic. The experimental group was 72.5% White, 15% African American, 2.5% Native American, 5% Asian, and 5% Hispanic, and the control group was 71.8% White, 23% African American, 2.6% Asian, and 2.6% Hispanic (Figure 4.3). Ninety-one percent of the participants were either freshmen (Year 1, 73%) or sophomores (Year 2, 18%). The overall mean for year in school (i.e. freshman, sophomore, etc.) was 1.44 ± 0.90, the experimental group mean for year in school was 1.43 ± 0.84, and the control group mean for year in school was 1.46 ± 0.97 (Figure 4.4). The overall sample population was 24.1% biology majors, 59.5% non-biology STEM majors, and 16.5% non-STEM majors. The experimental group was 32.5% biology majors, 50% non-biology STEM majors, and 17.5% non-STEM majors, and the control group was 15.4% biology majors, 69.2% non-biology STEM majors, and 15.4% non-STEM majors (Figure 4.5).
Figure 4.1. Frequency Percent of Student Age for Experimental and Control Treatment Groups. Experimental mean: 20.53 ± 5.11; Control mean: 19.46 ± 3.09.

Figure 4.2. Percent of Student Gender for Experimental and Control Treatment Groups.
Figure 4.3. Percent of Student Race for Experimental and Control Treatment Groups.

Figure 4.4. Percent of Student Year in School for Experimental and Control Treatment Groups. Experimental mean: $1.43 \pm 0.84$; Control mean: $1.46 \pm 0.97$. 
Objective 1

The first objective of this research study was to compare students receiving the experimental treatment who are explicitly instructed in scientific explanation and argument and a control group of students instructed through traditionally-designed biology laboratories. This objective was broken into four components: (a) student ability to construct written scientific explanations and arguments, (b) student biological content knowledge, (c) student ability to write a formal laboratory report, and (d) student perception of biology as a discipline of science. Each of these components is addressed below comparing the students receiving the experimental treatment to the students who received the control treatment.

Student Ability to Construct Written Scientific Explanations and Arguments

Will explicit instruction in scientific explanation and argumentation (experimental) improve student ability to construct written scientific explanations and
arguments, over students instructed through traditionally-designed laboratories (control)?

To address this research question, the null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student ability to construct written scientific explanations and arguments, and the alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will improve student ability to construct written scientific explanations and arguments, were tested using an analysis of covariance (ANCOVA). Seventy-eight of the 79 participants, of which 39 were in the experimental group and 39 were in the control group, completed both the pretest and the posttest for the assessment of construction of written scientific explanation and argument. The independent variable was the treatment groups, experimental and control groups. The dependent variable was the increase from the pretest to the overall posttest written scientific explanation and argument score, which was calculated by subtracting the pretest score from the posttest score. If a student earned a higher score on the pretest than the posttest, the student had negative score. A student could earn a maximum score of 12 on the written scientific explanation and argument pretest and posttest. For increase from pretest to overall posttest written scientific explanation and argument score the experimental group had a mean score of $4.84 \pm 3.42$, a maximum score of 10.5, and a minimum score of -6.0; while the control group had a mean score of $2.12 \pm 2.61$, a maximum score of 9.0, and a minimum score of -3.0 (Table 4.1). The covariate was the pretest written scientific explanation and argument score. The experimental and control groups had similar pretest written scientific explanation and argument scores (Table 4.2). There was a linear relationship between pretest and the increase from pretest to overall posttest written scientific explanation and argument scores as assessed by visual
Table 4.1. Adjusted and Unadjusted Treatment Means and Variability for Increase from Pretest to Overall Posttest Written Scientific Explanation and Argument with Pretest Written Scientific Explanation and Argument Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 2.45. \(N\) = number of participants. \(M\) = mean. \(SD\) = Standard Deviation. \(SE\) = Standard Error.

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Table 4.2. The Covariate: Pretest Written Scientific Explanation and Argument Score. \(N\) = number of participants. \(M\) = mean. \(SD\) = Standard Deviation. \(Min\) = minimum score. \(Max\) = maximum score. The means for the experimental and control treatment groups are not statistically different (\(t = 0.59, p = 0.56\)).

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<td>2.61</td>
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inspection of a scatter plot (Figure 4.6). There was homogeneity of the regression slopes as the interaction between pretest scores and treatment groups was not significant, \(F(1,74) = 3.219, p = 0.08\). Standardized residuals for increase from pretest to overall posttest written scientific explanation and argument scores for the overall model and the control group were normally distributed as assessed by Shapiro-Wilk’s test, \((p > 0.05)\). The standardized residuals for the experimental group were not normally distributed as assessed by the Shapiro-Wilk’s test, \((p = 0.03)\). However, the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al 2003, p 345).

There was homoscedasticity as assessed through visual inspection of a scatter plot showing equal distribution of standardized residuals for predicted values of increase from pretest to overall posttest written scientific explanation and argument score (Figure 4.7). There was homogeneity of variance as assessed through Levene’s Test of Equality Error Variances, \(F(1,76) = 0.052, p = 0.82\). There were no outliers in the data as assessed by no existing cases with standardized residuals greater than \(\pm 3\) standard deviations. After
Figure 4.6. The Linear Relationship between Pretest and Increase from Pretest to Overall Posttest Written Scientific Explanation and Argument Scores. Experimental: $R^2 = 0.509$. Control: $R^2 = 0.209$.

Figure 4.7. Distribution of Standardized Residuals for Predicted Values of Increase from Pretest to Overall Posttest Written Scientific Explanation and Argument Score.
adjustment for pretest written scientific explanation and argument scores, there was a statistically significant difference between experimental and control treatment groups for increase from pretest to overall posttest written scientific explanation and argument scores, $F(1,75) = 28.919, p = 0.00$, partial $\eta^2 = 0.28, \hat{\eta}^2 = 0.20$. Students in the experimental treatment group had statistically significantly higher adjusted mean scores on increase from pretest to overall posttest written scientific explanations and arguments than students in the control treatment group (Figure 4.8, Table 4.1).

![Graph showing adjusted means for increase from pretest to overall posttest written scientific explanation and argument score](image)

Figure 4.8. Affect of Treatment on Adjusted Means for Increase from Pretest to Overall Posttest Written Scientific Explanation and Argument Score with Pretest Written Scientific Explanation and Argument Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 2.45. The adjusted means for the treatment groups are significantly different. Experimental Adjusted Mean = 4.96 ± 0.39; Control Adjusted Mean = 2.00 ± 0.39; $F(1,75) = 28.919, p = 0.00$, partial $\eta^2 = 0.28, \hat{\eta}^2 = 0.20$.

**Student Biological Content Knowledge**

Will explicit instruction in scientific explanation and argumentation (experimental) improve student biological content knowledge, over students instructed
through traditionally-designed laboratories (control)? To address this research question, the null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student biological content knowledge, and the alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will improve student biological content knowledge, were tested using an analysis of covariance (ANCOVA). Seventy-nine of the 96 students, of which 40 were in the experimental group and 39 were in the control group, completed both the pretest and the posttest for the assessment of biological content knowledge. The independent variable was the treatment groups, experimental and control groups. The dependent variable was the increase from the pretest to the posttest biological content knowledge score, which was calculated by subtracting the pretest score from the posttest score. If a student earned a higher score on the pretest than the posttest, the student had negative score. A student could earn a maximum score of 100 on the biological content knowledge pretest and posttest. For increase from pretest to posttest biological content knowledge the experimental group had a mean score of $35.58 \pm 14.85$, a maximum score of 66, and a minimum score of 8; while the control group had a mean score of $29.67 \pm 18.24$, a maximum score of 63, and a minimum score of -10 (Table 4.3). The covariate was the pretest biological content knowledge score. The experimental and control groups had similar pretest biological content knowledge scores (Table 4.4). There was a linear relationship between pretest and the increase from pretest to posttest content knowledge scores as assessed by visual inspection of a scatter plot (Figure 4.9). There was homogeneity of the regression slopes as the interaction term between pretest scores and treatment groups was not significant, $F(1,75) = 1.587$, $p = 0.21$. Standardized residuals for increase from pretest to posttest biological content knowledge score for the
Table 4.3. Adjusted and Unadjusted Treatment Means and Variability for Increase from Pretest to Posttest Biological Content Knowledge Score with Pretest Biological Content Knowledge Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 44.51. $N$ = number of participants. $M$ = mean. $SD$ = Standard Deviation. $SE$ = Standard Error.

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<td>Control</td>
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<td>29.67</td>
<td>18.24</td>
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Table 4.4. The Covariate: Pretest Biological Content Knowledge Score. $N$ = number of participants. $M$ = mean. $SD$ = Standard Deviation. Min = minimum score. Max = maximum score. The means for the experimental and control treatment groups are not statistically different ($t = -1.67$, $p = 0.10$).

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<td>Control</td>
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<td>14.51</td>
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Figure 4.9. The Linear Relationship between Pretest and Increase from Pretest to Posttest Biological Content Knowledge Scores. Experimental: $R^2 = 0.139$. Control: $R^2 = 0.345$. 
overall model and the experimental and control group were normally distributed as assessed by Shapiro-Wilk’s test, \( p > 0.05 \). There was homoscedasticity as assessed through visual inspection of a scatter plot showing equal distribution of standardized residuals for predicted values of increase from pretest to posttest content knowledge score (Figure 4.10). There was homogeneity of variance as assessed through Levene’s Test of Equality Error Variances \( (F(1,77) = 0.665, p = 0.42) \). There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations. After adjustment for pretest biological content knowledge score there was not a statistically significant difference between the experimental and control treatment groups, \( F(1,76) = 0.717, p = 0.40 \), partial \( \eta^2 = 0.01 \), \( \bar{\eta}^2 = 0.01 \) (Figure 4.11, Table 4.3).

Figure 4.10. Distribution of Standardized Residuals for Predicted Values of Increase from Pretest to Posttest Content Knowledge Score.
Student Ability to Write a Formal Laboratory Report

Will explicit instruction in scientific explanation and argumentation (experimental) improve student ability to write a formal laboratory report, over students instructed through traditionally-designed laboratories (control)? To address this research question, the null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student ability to write a formal laboratory report, and the alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will improve student ability to write a formal written laboratory report, were tested using an analysis of covariance (ANCOVA). Seventy-five students, of which 40 were in the experimental group and 35 were in the control group, turned in a formal written laboratory report. The

Figure 4.11. Affect of Treatment on Adjusted Means for Increase from Pretest to Posttest Biological Content Knowledge Score with Pretest Biological Content Knowledge Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 44.51. The adjusted means for the treatment groups are not significantly different. Experimental Adjusted Mean = 34.05 ± 2.32; Control Adjusted Mean = 31.23 ± 2.35; $F(1,76) = 0.717$, $p = 0.40$, partial $\eta^2 = 0.01$, $\eta^2 = 0.01$. 
independent variable was the treatment groups, experimental and control groups. The dependent variable was the laboratory report score out of 50 possible points. For written formal laboratory reports the experimental group had a mean score of 39.24 ± 4.87, a maximum score of 47.5, and a minimum score of 24.5; while the control group had a mean score of 37.41 ± 7.16, a maximum score of 48, and a minimum score of 20.5 (Table 4.5). The covariate was high school grade point average (GPA). The experimental and control groups had similar high school GPA (Table 4.6). There was a linear relationship between high school GPA and laboratory report scores as assessed by visual inspection of a scatter plot (Figure 4.12). There was homogeneity of the regression slopes as the interaction term between pretest scores and treatment groups was not significant, $F(1,71) = 3.192, p = 0.09$. Standardized residuals for increase from pretest to posttest biological content knowledge score for the overall model and the experimental and control group were normally distributed as assessed by Shapiro-Wilk’s test, ($p > 0.05$). There was homoscedasticity as assessed through visual inspection of a scatter plot showing equal distribution of standardized residuals for laboratory report scores (Figure 4.13). There was homogeneity of variance as assessed through Levene’s Test of Equality Error Variances, $F(1,73) = 0.381, p = 0.54$. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations. After adjustment for high school GPA, there was not a statistically significant difference between the experimental and control treatment groups adjusted mean scores for writing formal laboratory reports, $F(1,72) = 3.446, p = 0.07$, partial $\eta^2 = 0.05$, $\eta^2 = 0.05$ (Figure 4.14, Table 4.5).
Table 4.5. Adjusted and Unadjusted Treatment Means and Variability for Laboratory Report Scores with High School Grade Point Average as a Covariate. Covariate evaluated at the following value: High School GPA = 3.28. N = number of participants. M = mean. SD = Standard Deviation. SE = Standard Error.

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<td>7.16</td>
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Table 4.6. The Covariate: High School GPA. N = number of participants. M = mean. SD = Standard Deviation. Min = minimum score. Max = maximum score. The means for the experimental and control treatment groups are not statistically different (t = -0.65, p = 0.52).

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Figure 4.12. The Linear Relationship between High School GPA and Laboratory Report Scores. Experimental: $R^2 = 0.160$. Control: $R^2 = 0.345$. 
Figure 4.13. Distribution of Standardized Residuals for Predicted Values of Laboratory Report Scores.

Figure 4.14. Affect of Treatment on Adjusted Means for Formal Laboratory Report Score with High School GPA as a Covariate. Covariate evaluated at the following value: High School GPA = 3.28. The adjusted means for the treatment groups are not significantly different. Experimental Adjusted Mean = 39.45 ± 0.84; Control Adjusted Mean = 37.17 ± 0.89; $F(1,72) = 3.446, p = 0.07$, partial $\eta^2 = 0.05$, $\eta^2 = 0.03$. 
**Student Perception of Biology as a Discipline of Science**

Will explicit instruction in scientific explanation and argumentation (experimental) influence student perception of biology as a discipline of science, over students instructed through traditionally-designed laboratories (control)? To address this research question, the null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student perception of biology as a discipline of science, and the alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will affect student perception of biology as a discipline of science, were tested using an analysis of covariance (ANCOVA). Seventy-five students, of which 37 were in the experimental group and 38 were in the control group, fully completed both the Colorado Learning Attitudes about Science Survey for Use in Biology Courses (CLASS-pbio) pretest and posttest for assessment of student perception of biology as a discipline of science. One outlier was removed from the experimental group as assessed by an existing case with a standardized residual greater than $\pm 3$ standard deviations for the dependent variable, resulting in 36 students in the experimental group. The independent variable was the treatment groups, experimental and control groups. The dependent variable was the CLASS-pbio posttest overall percent favorable score. For the CLASS-pbio posttest overall percent favorable score the experimental group had a mean score of 61.70 $\pm$ 18.92, a maximum score of 90.32, and a minimum score of 16.13; while the control group had a mean score of 60.01 $\pm$ 21.15, a maximum score of 93.33, and a minimum score of 16.13 (Table 4.7). The covariate was the CLASS-pbio pretest overall percent favorable score. The experimental and control groups had similar CLASS-pbio pretest overall percent favorable scores (Table 4.8). There was a linear relationship between
Table 4.7. Adjusted and Unadjusted Treatment Means and Variability for CLASS-bio Posttest Overall Percent Favorable Score with CLASS-bio Pretest Overall Percent Favorable Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 57.41. N = number of participants. M = mean. SD = Standard Deviation. SE = Standard Error.

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Table 4.8. The Covariate: CLASS-bio Pretest Overall Percent Favorable Score. N = number of participants. M = mean. SD = Standard Deviation. Min = minimum score. Max = maximum score. The means for the experimental and control treatment groups are not statistically different (t = -0.65, p = 0.52).

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<td>Control</td>
<td>59.68</td>
<td>17.98</td>
<td>25.81</td>
<td>96.77</td>
</tr>
</tbody>
</table>

CLASS-bio pretest and posttest overall percent favorable scores as assessed by visual inspection of a scatter plot (Figure 4.15). There was homogeneity of the regression slopes as the interaction term between pretest scores and treatment groups was not significant, F(1,70) = 0.461, p = 0.50. Standardized residuals for CLASS-bio posttest overall percent favorable score for the overall model and the experimental and control groups were normally distributed as assessed by Shapiro-Wilk’s test, (p > 0.05). There was homoscedasticity as assessed through visual inspection of a scatter plot showing equal distribution of standardized residuals for predicted values of CLASS-bio posttest overall percent favorable score (Figure 4.16). There was homogeneity of variance as assessed through Levene’s Test of Equality Error Variances, F(1,72) = 0.715, p = 0.40. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations, as one outlier was detected and removed prior to this ANCOVA (see above). After adjustment for CLASS-bio pretest overall percent favorable score, there was a statistically significant difference between
Figure 4.15. The Linear Relationship between CLASS-bio Pretest and Posttest Overall Percent Favorable Scores. Experimental: $R^2 = 0.548$. Control: $R^2 = 0.660$.

Figure 4.16. Distribution of Standardized Residuals for Predicted Values of CLASS-bio Posttest Overall Percent Favorable Score.
experimental and control treatment groups for CLASS-bio posttest overall percent favorable scores, $F(1,71) = 3.957$, $p = 0.05$, partial $\eta^2 =0.05$, $\bar{\eta}^2 =0.02$. Students in the experimental treatment group had statistically significantly higher adjusted mean CLASS-bio posttest overall percent favorable scores than students in the control treatment group (Figure 4.17, Table 4.7).

![Adjusted Means for CLASS-bio Posttest Overall Percent Favorable Score](image)

**Figure 4.17.** Affect of Treatment on Adjusted Means for CLASS-bio Posttest Overall Percent Favorable Score with CLASS-bio Pretest Overall Percent Favorable Score as a Covariate. Covariate evaluated at the following value: Pretest Score = 57.41. The adjusted means for the treatment groups are significantly different. Experimental Adjusted Mean = $63.86 \pm 2.12$; Control Adjusted Mean = $57.96 \pm 2.06$; $F(1, 71) = 3.957$, $p = 0.05$, partial $\eta^2 =0.05$, $\bar{\eta}^2 =0.02$.

**Objective 2**

The second objective of this research study was to evaluate student progress of ability to write scientific explanations and arguments over the course of the semester. Students receiving explicit instruction in scientific explanation and argumentation wrote six explanations and arguments over the course of the semester. Will students’ ability to
write scientific explanations and argument continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? To address this research question, the null hypothesis (H\(_0\)), which states: student ability to write scientific explanations and arguments will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), and the alternative hypothesis (H\(_A\)), which states: student ability to write scientific explanations and arguments will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), were tested using repeated measures analysis of variance (ANOVA). Thirty-four students receiving explicit instruction in scientific explanation and argumentation turned in all six written scientific explanations and arguments over the course of the semester. The independent variable was time over the course of the semester. The dependent variable was written scientific explanation and argument scores. Scores from the same individual were dependent samples, while scores from different individuals were independent samples. For each time a written scientific explanation and argument was collected, there were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations. For three (Weeks 2, 6, and Final Exam) of the six times written scientific explanation and argument was collected there was a normal distribution of the dependent variable as was assessed using the Shapiro-Wilk’s test \((p > 0.05)\). However, the remaining three times (Pretest, Weeks 1, and 9) the dependent variable was not normally distributed as assessed by the Shapiro-Wilk’s test, \((p < 0.05)\). However, the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al, 2003, p 345). Mauchley’s test for sphericity was significant \(\chi^2(14) = 27.70, p = 0.02\), therefore the assumption of sphericity was
violated. When sphericity is violated, the Type I error rate can be affected. A correction
to the degrees of freedom can provide a conservative \( F \) value and statistical test for the
null hypothesis, to compensate for the Type I error rate (Hinkle et al, 2003, p. 261),
therefore Greenhouse-Geisser was applied (\( \varepsilon = 0.777 \)). Student written scientific
explanation and argument scores showed statistically significant changes over the course
of the semester \( F(3.886,128.249) = 78.463, p = 0.000, \text{partial } \eta^2 = 0.704 \) (Figure 4.18 and
Table 4.9). Post hoc analysis with a Bonferroni adjustment was used. There was a

<table>
<thead>
<tr>
<th>Time</th>
<th>Week</th>
<th>Scientific Explanation and Argument</th>
<th>( N )</th>
<th>( M )</th>
<th>( SD )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pretest</td>
<td>34</td>
<td>2.21(^a)</td>
<td>1.45</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Termite Activity</td>
<td>34</td>
<td>9.07(^b,c)</td>
<td>2.33</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Goldfish Cellular Respiration Experiment</td>
<td>34</td>
<td>7.62(^b)</td>
<td>1.96</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Diffusion and Osmosis Experiment</td>
<td>34</td>
<td>8.56(^b)</td>
<td>1.88</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Photosynthesis Experiment</td>
<td>34</td>
<td>9.88(^c)</td>
<td>1.25</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>Posttest</td>
<td>34</td>
<td>7.68(^b)</td>
<td>2.37</td>
</tr>
</tbody>
</table>

statistically significant increase of 6.87 (95% CI, 5.32 to 8.41), \( p = 0.00 \), from the mean
pretest (Time 1) written scientific explanation and argument score of 2.21 ± 1.45 to the
mean termite activity (Time 2) written scientific explanation and argument score of 9.07
± 2.33, which were produced by students during Week 1 of the semester after explicit
instruction in scientific explanation and argument. Additionally, the mean pretest (Time
1) written scientific explanation and argument score of 2.21 ± 1.45 was significantly
lower (\( p = 0.00 \)) than all the following mean written scientific explanation and argument
scores collected over the duration of the semester. There was a slight decrease of -1.46 (\( p
> 0.05 \)) from the mean termite activity (Time 2) written scientific explanation and
argument score of 9.07 ± 2.33 to the mean goldfish cellular respiration experiment (Time 3) written scientific explanation and argument score of 7.62 ± 1.96. Followed by a slight increase of 0.94 ($p > 0.05$), from the mean goldfish cellular respiration experiment (Time 3) written scientific explanation and argument score of 7.62 ± 1.96 to the mean diffusion and osmosis experiment (Time 4) written scientific explanation and argument score of 8.56 ± 1.88. The increase from the mean goldfish cellular respiration experiment (Time 3) written scientific explanation and argument score of 7.62 ± 1.96 to the mean photosynthesis experiment (Time 5) written scientific explanation and argument score of 9.88 ± 1.25 was a statistically significant increase of 2.27 (95% CI, 1.18 to 3.35), $p = 0.00$. Additionally, the increase from mean diffusion and osmosis experiment (Time 4)
written scientific explanation and argument score of 8.56 ± 1.88 to the mean photosynthesis experiment (Time 5) written scientific explanation and argument score of 9.88 ± 1.25 was a statistically significant increase of 1.32 (95% CI, 0.39 to 2.26), \( p = 0.00 \). Finally, there was a statistically significant decrease of -2.21 (95% CI, -3.40 to -1.01), \( p = 0.00 \), from mean photosynthesis experiment (Time 5) written scientific explanation and argument score of 9.88 ± 1.25 to the mean posttest (Time 6) written scientific explanation and argument score of 7.68±2.37 (Figure 4.18 and Table 4.9).

To more completely evaluate student progress of ability to write scientific explanations and arguments over the course of the semester, the six scientific explanations and arguments written by students, who received explicit instruction in scientific explanation and argumentation over the course of the semester, were broken down into four components: claim, evidence, reasoning, and counter argument. Each of these components of written scientific explanations and arguments is addressed below.

**Claim**

Will students’ ability to write claims in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? To address this research question, the null hypothesis \( (H_0) \), which states: student ability to write claims will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), and the alternative hypothesis \( (H_A) \), which states: student ability to write claims will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), were tested using repeated measures ANOVA. After removal of outliers, 32 of the 34 students receiving explicit instruction in scientific explanation and argumentation and who turned in all six written
scientific explanations and arguments over the course of the semester were used to test these hypotheses. The independent variable was time over the course of the semester. The dependent variable was written claim scores. Scores from the same individual were dependent samples, whereas scores from different individuals were independent samples. The data was assessed for outliers for each time a written scientific explanation and argument was collected. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations for claim scores collected during the Pretest, Weeks 2 and 6, and the Posttest. There were three outliers detected as assessed by existing cases with standardized residuals greater than ±3 standard deviations for claim scores collected during Week 1 and 9. The two outliers detected from Week 1 included claim scores of 0 and 1 were removed from the data set as all other claim scores from Week 1 were 2.5 and above. The single outlier detected from Week 9 was a claim score of 2, which was not removed from the data set as all other claim scores from Week 9 were 3. For all six times written scientific explanations and arguments were collected, the dependent variable was not normally distributed as assessed by the Shapiro-Wilk’s test, \( p < 0.05 \). However, the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al, 2003, p 345). Mauchley’s test for sphericity was significant \( \chi^2(14) = 71.907, p = 0.00 \), therefore the assumption of sphericity was violated. When sphericity is violated, the Type I error rate can be affected. A correction to the degrees of freedom can provide a conservative \( F \) value and statistical test for the null hypothesis, to compensate for the Type I error rate (Hinkle et al, 2003, p. 261), therefore Greenhouse-Geisser was applied \( (\varepsilon = 0.506) \). Student claim scores showed statistically significant changes over the course of the
semester $F(2.529,78.404) = 45.163$, $p = 0.000$, partial $\eta^2 = 0.593$ (Figure 4.19 and Table 4.10). Post hoc analysis with a Bonferroni adjustment was used. There was a statistically significant increase of 1.42 (95% CI, 0.87 to 1.98), $p = 0.00$, from mean pretest (Time 1) claim score of 1.41 ± 0.87 to the mean termite activity (Time 2) claim score of 2.83 ± 0.24, which were produced by students during Week 1 of the semester after explicit instruction in scientific explanation and argument. Additionally, the mean pretest (Time 1) claim score of 1.41 ± 0.87 was significantly lower ($p = 0.00$) than all the following mean claim scores collected over the duration of the semester. The mean termite activity (Time 2) claim score of 2.83 ± 0.24, the mean goldfish cellular respiration experiment (Time 3) claim score of 2.84 ± 0.37, the mean diffusion and osmosis experiment (Time 4) claim score of 2.81 ± 0.40, and the mean photosynthesis experiment (Time 5) claim score of 2.97 ± 0.18 were not statistically significantly different ($p = 1.00$). There was a statistically significant decrease of 0.36 (95% CI, -0.68 to -0.03), $p = 0.02$, from mean photosynthesis experiment (Time 5) claim score of 2.97 ± 0.18 to the mean posttest (Time 6) claim score of 2.61 ± 0.53 (Figure 4.19 and Table 4.10).

Table 4.10. Mean Claim Scores Collected Over the Duration of the Semester. $N =$ number of participants. $M =$ mean. $SD =$ Standard Deviation. $a, b, c$ Different letters represent statistically significant values ($p < 0.05$).

<table>
<thead>
<tr>
<th>Time</th>
<th>Week</th>
<th>Scientific Explanation and Argument</th>
<th>$N$</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pretest</td>
<td>32</td>
<td>1.41$^a$</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Termite Activity</td>
<td>32</td>
<td>2.83$^{b,c}$</td>
<td>0.24</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Goldfish Cellular Respiration</td>
<td>32</td>
<td>2.84$^{b,c}$</td>
<td>0.37</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Diffusion and Osmosis Experiment</td>
<td>32</td>
<td>2.81$^{b,c}$</td>
<td>0.40</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Photosynthesis Experiment</td>
<td>32</td>
<td>2.97$^b$</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>Posttest</td>
<td>32</td>
<td>2.61$^c$</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Evidence

Will students’ ability to write evidence in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? To address this research question, the null hypothesis ($H_0$), which states: student ability to write evidence will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), and the alternative hypothesis ($H_A$), which states: student ability to write evidence will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), were tested using repeated measures ANOVA. After removal of outliers, 27 of the 34 students receiving explicit instruction in scientific explanation and argumentation, who turned in all six
written scientific explanations and arguments over the course of the semester, were used to test these hypotheses. The independent variable was time over the course of the semester. The dependent variable was written evidence scores. Scores from the same individual were dependent samples, whiles scores from different individuals were independent samples. The data was assessed for outliers for each time a written scientific explanation and argument was collected. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations for evidence scores collected during the Weeks 2 and the Posttest. There were ten outliers detected as assessed by existing cases with standardized residuals greater than ±3 standard deviations for evidence scores collected during the Pretest and Week 1, 6, and 9. The three outliers detected from the Pretest included evidence scores of 3, 2, and 2 and were removed from the data set as all other evidence scores from the Pretest were 0. The three outliers detected from Week 1 included evidence scores of 0 and were removed from the data set as all other evidence scores from Week 1 were 2 and above. The single outlier detected from Week 6 was an evidence score of 0 and was removed from the data set as all other evidence scores from Week 6 were 2 and above. The three outlier detected from Week 9 were evidence scores of 2, which were not removed from the data set as all other claim scores from Week 9 were 3. For all six times written scientific explanations and arguments were collected, the dependent variable was not normally distributed as assessed by the Shapiro-Wilk’s test, \( p < 0.05 \). However, the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al, 2003). Mauchley’s test for sphericity was significant \( \chi^2(14) = 93.963, p = 0.00 \), therefore the assumption of sphericity was violated. When sphericity is violated, the Type I error rate
can be affected. A correction to the degrees of freedom can provide a conservative $F$ value and statistical test for the null hypothesis, to compensate for the Type I error rate (Hinkle et al, 2003, p. 261), therefore Greenhouse-Geisser was applied ($\varepsilon = 0.467$).

Student evidence scores changed significantly over the course of the semester

\[ F(2.333,60.657) = 96.928, p = 0.00, \text{ partial } \eta^2 = 0.788 \] (Figure 4.20 and Table 4.11).

Table 4.11. Mean Evidence Scores Collected Over the Duration of the Semester. $N =$ number of participants. $M =$ mean. $SD =$ Standard Deviation. $a, b, c, d$ Different letters represent statistically significant values ($p < 0.05$).

<table>
<thead>
<tr>
<th>Time</th>
<th>Week</th>
<th>Scientific Explanation and Argument</th>
<th>$N$</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pretest</td>
<td>27</td>
<td>0.00$^a$</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Termite Activity</td>
<td>27</td>
<td>2.91$^b$</td>
<td>0.28</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Goldfish Cellular Respiration Experiment</td>
<td>27</td>
<td>0.98$^c$</td>
<td>1.24</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Diffusion and Osmosis Experiment</td>
<td>27</td>
<td>2.70$^b$</td>
<td>0.47</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Photosynthesis Experiment</td>
<td>27</td>
<td>2.89$^b$</td>
<td>0.32</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>Posttest</td>
<td>27</td>
<td>1.81$^d$</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Post hoc analysis with a Bonferroni adjustment was used. There was a statistically significant increase of 2.91 (95% CI, 2.73 to 3.08), $p = 0.00$, from mean pretest (Time 1) evidence score of $0.00 \pm 0.00$ to the mean termite activity (Time 2) evidence score of $2.91 \pm 0.28$, which were produced by students during Week 1 of the semester after explicit instruction in scientific explanation and argument. Additionally, the mean pretest (Time 1) evidence score of $0.00 \pm 0.00$ was significantly lower ($p < 0.05$) than all of the following mean written evidence scores collected over the duration of the semester.

There was a statistically significant decrease of -1.93 (95% CI, -2.73 to -1.12), $p = 0.00$, from mean termite activity (Time 2) evidence score of $2.91 \pm 0.28$ to the mean goldfish cellular respiration experiment (Time 3) evidence score of $0.98 \pm 1.24$. Additionally, the mean goldfish cellular respiration experiment (Time 3) evidence score of $0.98 \pm 1.24$ was significantly lower ($p <0.05$) than the mean explanation scores for the diffusion and
osmosis experiment (Time 4), the photosynthesis experiment (Time 5), and the posttest (Time 6) respectively. The mean termite activity (Time 2) evidence score of 2.91 ± 0.28, the mean diffusion and osmosis experiment (Time 4) evidence score of 2.20 ± 0.47, and the mean photosynthesis experiment (Time 5) evidence score of 2.89 ± 0.32 were not statistically significantly different ($p > 0.05$). There was a statistically significant decrease of -1.08 (95% CI, -1.64 to -0.53), $p = 0.00$, from mean photosynthesis experiment (Time 5) evidence score of 2.89 ± 0.32 to the mean posttest (Time 6) evidence score of 1.81 ± 0.89. Additionally, the mean posttest (Time 6) evidence score of 1.81 ± 0.89 was statistically significantly lower ($p = 0.00$) than the mean termite
activity (Time 2) evidence score of 2.91 ± 0.28, the mean diffusion and osmosis experiment (Time 4) evidence score of 2.20 ± 0.47 (Figure 4.20 and Table 4.11).

Reasoning

Will students’ ability to include reasoning in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? To address this research question, the null hypothesis ($H_0$), which states: student ability to write reasoning will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), and the alternative hypothesis ($H_A$), which states: student ability to write reasoning will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), were tested using repeated measures ANOVA. Thirty-four students receiving explicit instruction in scientific explanation and argumentation, who turned in all six written scientific explanations and arguments over the course of the semester, were used to test these hypotheses. The independent variable was time over the course of the semester. The dependent variable was written reasoning scores. Scores from the same individual were dependent samples, whiles scores from different individuals were independent samples. The data was assessed for outliers for each time a written scientific explanation and argument was collected. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations for reasoning scores collected over the course of the semester. For all six times written scientific explanations and arguments were collected, the dependent variable was not normally distributed as assessed by the Shapiro-Wilk’s test, ($p < 0.05$). However, the effect of violating the assumption of normality on Type I error rate is minimal (Hinkle et al, 2003). Mauchley’s
test for sphericity was significant $\chi^2(14) = 35.773, p = 0.00$, therefore the assumption of sphericity was violated. When sphericity is violated, the Type I error rate can be affected. A correction to the degrees of freedom can provide a conservative $F$ value and statistical test for the null hypothesis, to compensate for the Type I error rate (Hinkle et al, 2003, p. 261), therefore Greenhouse-Geisser was applied ($\varepsilon = 0.739$). Student reasoning scores showed statistically significant changes over the course of the semester $F(3.694,121.915) = 37.255, p = 0.000$, partial $\eta^2 =0.530$ (Figure 4.21 and Table 4.12).

<table>
<thead>
<tr>
<th>Time</th>
<th>Week</th>
<th>Scientific Explanation and Argument</th>
<th>$N$</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pretest</td>
<td>34</td>
<td>0.53\textsuperscript{a}</td>
<td>0.66</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Termite Activity</td>
<td>34</td>
<td>2.28\textsuperscript{b}</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Goldfish Cellular Respiration Experiment</td>
<td>34</td>
<td>2.46\textsuperscript{b,c}</td>
<td>0.66</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Diffusion and Osmosis Experiment</td>
<td>34</td>
<td>1.75\textsuperscript{b}</td>
<td>0.99</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Photosynthesis Experiment</td>
<td>34</td>
<td>2.68\textsuperscript{c}</td>
<td>0.47</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>Posttest</td>
<td>34</td>
<td>2.15\textsuperscript{b,d}</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Post hoc analysis with a Bonferroni adjustment was used. There was a statistically significant increase of 1.75 (95% CI, 1.31 to 2.19), $p = 0.00$, from mean pretest (Time 1) reasoning score of $0.53 \pm 0.66$ to the mean termite activity (Time 2) reasoning score of $2.28 \pm 1.02$, which were produced by students during Week 1 of the semester after explicit instruction in scientific explanation and argument. Additionally, the mean pretest (Time 1) reasoning score of $0.53 \pm 0.66$ was significantly lower than all of the following mean written evidence scores collected over the duration of the semester ($p = 0.00$). There was a slight increase of 0.18 ($p > 0.05$) from mean termite activity (Time 2) reasoning score of $2.28 \pm 1.02$ to the mean goldfish cellular respiration experiment (Time 3) reasoning score of $2.46 \pm 0.66$. Also, the mean termite activity (Time 2) reasoning score of $2.28 \pm 1.02$ is significantly higher than the mean diffusion and osmosis (Time 4)
reasoning score of 1.75 ± 0.99 ($p = 0.02$) and significantly lower than the mean photosynthesis (Time 5) reasoning score of 2.68 ± 0.47 ($p = 0.04$). There was a significant decrease of -0.71 (95% CI, -1.14 to -0.27), $p = 0.00$, from the mean goldfish cellular respiration experiment (Time 3) reasoning score of 2.46 ± 0.66 to the mean diffusion and osmosis (Time 4) reasoning score of 1.75 ± 0.99. Additionally, the mean goldfish cellular respiration experiment (Time 3) reasoning score of 2.46 ± 0.66 was significantly higher ($p = 0.01$) than the mean explanation score for the posttest (Time 6) of 2.15 ± 0.67. There was a significant increase of 0.93 (95% CI 0.56 to 1.29), $p = 0.00$, from the mean diffusion and osmosis (Time 4) reasoning score of 1.75 ± 0.99 to the mean photosynthesis experiment (Time 5) reasoning score of 2.68 ± 0.47. There was a
statistically significant decrease of -0.52 (95% CI, -0.76 to -0.28), \( p = 0.00 \), from mean photosynthesis experiment (Time 5) reasoning score of 2.68 ± 0.47 to the mean posttest (Time 6) evidence score of 2.15 ± 0.67 (Figure 4.21 and Table 4.12).

**Counter Argument**

Will students’ ability to write counter arguments in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? To address this research question, the null hypothesis (\( H_0 \)), which states: student ability to write counter arguments will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), and the alternative hypothesis (\( H_A \)), which states: student ability to write counter arguments will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), were tested using repeated measures ANOVA. Thirty-four students receiving explicit instruction in scientific explanation and argumentation, who turned in all six written scientific explanations and arguments over the course of the semester, were used to test these hypotheses. The independent variable was time over the course of the semester. The dependent variable was written counter argument scores. Scores from the same individual were dependent samples, while scores from different individuals were independent samples. The data was assessed for outliers for each time a written scientific explanation and argument was collected. There were no outliers in the data as assessed by no existing cases with standardized residuals greater than ±3 standard deviations for counter argument scores collected over the course of the semester. For all six times written scientific explanations and arguments were collected, the dependent variable was not normally distributed as assessed by the Shapiro-Wilk’s test, (\( p < 0.05 \)). However,
the effect of violating the assumption of normality on Type I error rate is minimal
(Hinkle et al, 2003). Mauchley’s test for sphericity was significant \( \chi^2(14) = 33.678, p = 0.00 \), therefore the assumption of sphericity was violated. When sphericity is violated, the Type I error rate can be affected. A correction to the degrees of freedom can provide a conservative \( F \) value and statistical test for the null hypothesis, to compensate for the Type I error rate (Hinkle et al, 2003, p. 261), therefore Greenhouse-Geisser was applied \((\epsilon = 0.722)\). Student counter argument scores changed significantly over the course of the semester \( F(3.612,119.187) = 12.614, p = 0.00, \) partial \( \eta^2 =0.277 \) (Figure 4.22 and Table 4.13). Post hoc analysis with a Bonferroni adjustment was used. There was a statistically significant increase of 1.44 (95% CI, 1.02 to 1.86), \( p = 0.00 \), from mean pretest (Time 1) counter argument score of 0.00 ± 0.00 to the mean termite activity (Time 2) counter argument score of 1.44 ± 1.21, which were produced by students during Week 1 of the semester after explicit instruction in scientific explanation and argument. Additionally, the mean pretest (Time 1) counter argument score of 0.00 ± 0.00 was significantly lower \((p = 0.00)\) than all of the following mean counter argument scores collected over the duration of the semester. The mean termite activity (Time 2) counter argument score of 1.44 ± 1.21, the mean goldfish cellular respiration experiment (Time 3) counter argument

<table>
<thead>
<tr>
<th>Time</th>
<th>Week</th>
<th>Scientific Explanation and Argument</th>
<th>( N )</th>
<th>( M )</th>
<th>( SD )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Pretest</td>
<td>34</td>
<td>0.00(^a)</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Termite Activity</td>
<td>34</td>
<td>1.44(^b)</td>
<td>1.21</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Goldfish Cellular Respiration Experiment</td>
<td>34</td>
<td>1.29(^b)</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Diffusion and Osmosis Experiment</td>
<td>34</td>
<td>1.43(^b)</td>
<td>1.27</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>Photosynthesis Experiment</td>
<td>34</td>
<td>1.32(^b)</td>
<td>0.88</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>Posttest</td>
<td>34</td>
<td>1.09(^b)</td>
<td>0.90</td>
</tr>
</tbody>
</table>
score of $1.29 \pm 0.90$, the mean diffusion and osmosis experiment (Time 4) counter argument score of $1.43 \pm 1.27$, and the mean photosynthesis experiment (Time 5) counter argument score of $1.32 \pm 0.88$, and the mean posttest (Time 6) counter argument score of $1.09 \pm 0.90$ were not statistically significantly different ($p > 0.05$) (Figure 4.22 and Table 4.13).

Figure 4.22. Mean Counter Argument Scores Collected Over the Duration of the Semester. Time 1: Week 1, Pretest. Time 2: Week 1, Termite Activity. Time 3: Week 2, Goldfish Respiration Experiment. Time 4: Week 6, Diffusion and Osmosis Experiment. Time 5: Week 9, Photosynthesis Experiment. Time 6: Week 14, Posttest. $a, b$ Different letters represent statistically significant values ($p < 0.05$).

Objective 3

The third objective was to understand how various demographic and academic variables can influence student ability to construct written scientific explanations and arguments. Standard multiple regression with significance set at $p = 0.05$, was used to answer the following question: What demographic and academic variables positively
influence student ability to construct written scientific explanations and arguments? Standard multiple regression was used to explain the variation in the dependent variable. Seventy-two of the 74 students who completed all assessments used to collect the dependent and independent variables discussed below were used to produce the standard multiple regression model, two students were removed as outliers (see below). The dependent variable was posttest written scientific explanation and argument score. The independent or influencing variables were gender, major, treatment, posttest biological content knowledge percentage score, and the CLASS-bio posttest overall percent favorable score. Each independent variable had a linear relationship with the dependent variable as assessed by visual inspection of scatter plots. Additionally, the model on a whole showed a linear relationship as assessed by the visual inspection of a scatter plot of the normal distribution of standardized residuals for predicted values of posttest written scientific explanation and arguments scores for the model. This scatter plot was also assessed to show the assumption of homoscedasticity was met. The assumption of no collinearity was met as assessed by no correlations among independent variables being greater the 0.40 and all collinearity tolerance values being greater than 0.1. Outliers and unusual data points were assessed, and two cases were excluded. One outlier was excluded as assessed by an existing case with standardized residuals greater than ±3 standard deviations. An unusual data point was excluded for showing risky leverage as assessed by a leverage value 0.20 > 0.50. Normality of standardized residuals was met as assessed by visual inspection of a histogram and P-P plots. The independent variables produced a statistically significant model to explain variation in student ability to write scientific explanations and arguments \( F(5, 66) = 22.719, p = 0.00, \text{adj. } R^2 = .605. \) Two of
the five independent variables added significantly to the model including treatment
(experimental vs. control), $\beta = -0.587$, $p = 0.00$, and posttest biological content
knowledge percentage score, $\beta = 0.506$, $p = 0.00$. 
CHAPTER 5.
DISCUSSION

This purpose of this research study was to implement a college level appropriately modified McNeill et al. (2006) Claim, Evidence, and Reasoning (CER) Framework as an instructional model for construction of scientific explanations and arguments in an undergraduate introductory biology laboratory course at a large university in Southeastern United States. Students receiving the experimental treatment who were explicitly instructed in construction of written scientific explanations and arguments were compared with students receiving the control treatment who were taught in traditionally-designed biology laboratories. Student progress of ability to write scientific explanations and arguments over the course of the semester was investigated for those students who received explicit instruction in scientific explanation and argument. Finally, the influence of various demographic and academic variables on student ability to construct written scientific explanations and arguments was investigated.

Objective 1

The first objective of this research study was to compare students receiving the experimental treatment who were explicitly instructed in scientific explanation and argument and a control group of students instructed through traditionally-designed biology laboratories. This objective was broken into four components: (a) student ability to construct written scientific explanations and arguments, (b) student biological content knowledge, (c) student ability to write a formal laboratory report, and (d) student perception of biology as a discipline of science. Each of these components is addressed below comparing the students receiving the experimental treatment to the students who received the control treatment.
Student Ability to Construct Written Scientific Explanations and Arguments

Will explicit instruction in scientific explanation and argumentation (experimental) improve student ability to construct written scientific explanations and arguments, over students instructed through traditionally-designed laboratories (control)?

The null hypothesis \( (H_0) \), which states: the treatment (experimental vs. control) will not affect student ability to construct written scientific explanations and arguments, was rejected. The alternative hypothesis \( (H_A) \), which states: the treatment (experimental vs. control) will improve student ability to construct written scientific explanations and arguments, failed to be rejected. Students in the experimental treatment group had statistically significantly higher adjusted mean scores on increase from pretest to overall posttest written scientific explanations and arguments than students in the control treatment group (Figure 4.8, Table 4.1). These findings are similar to findings in science education literature. Across grade levels from middle school to undergraduate and domains including biology, chemistry, physics, and science education classes, explicit instruction in scientific explanations and arguments has resulted in higher quality written scientific explanations and arguments (Lizotte et al., 2004; McNeill & Krajcik, 2009; Nussbaum et al., 2008; Stark et al., 2009; Zembal-Saul et al., 2002; Zohar & Nemet, 2002). Though past research has shown the positive effect of explicit instruction on construction of scientific explanation and argument by undergraduate level students in education courses, biochemistry courses, and chemistry laboratories (Hand & Choi, 2010; Johnson, 2011; Walker et al., 2012), this research study demonstrated there is also a positive effect of explicit instruction on construction of scientific explanations and arguments by undergraduate students in biology laboratory courses.
Student Biological Content Knowledge

Will explicit instruction in scientific explanation and argumentation (experimental) improve student biological content knowledge, over students instructed through traditionally-designed laboratories (control)? The null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student biological content knowledge, failed to be rejected. The alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will improve student biological content knowledge, was rejected. There was not a statistically significant difference between the experimental and control treatment groups for increase from pretest to posttest biological content knowledge score (Figure 4.11, Table 4.3). While this study rejected the hypothesis that explicit instruction in scientific explanation and argumentation can improve student scientific content knowledge, it supports that students who engage in the time consuming process of constructing written scientific explanations and arguments did not miss out on gaining content knowledge, which is similar to findings for use of Argument-Driven Inquiry in undergraduate chemistry laboratories (Walker et al., 2012). However, past studies have also resulted in improved understanding of scientific content knowledge for students across grade levels from middle school to undergraduate in biology, chemistry, and physics courses (Bell & Linn, 2000; McNeill et al., 2006; Nussbaum et al., 2008; Zohar & Nemet, 2002). As students construct written scientific explanations and arguments, they are able to construct meanings of science concepts as evidence and claims are tied together through reasoning (Berland & Reiser, 2009; McNeill & Krajcik, 2009). The majority of student participants in this research study for both the experimental and control groups were concurrently enrolled in an undergraduate
introductory biology lecture course covering the same topics as taught in the introductory biology laboratory course. The lecture courses were taught by nine different instructors, who also may have provided opportunities for students to construct meanings of science concepts discussed in the introductory biology laboratory course and assessed by the biology content knowledge posttest used in this research study.

**Student Ability to Write a Formal Laboratory Report**

Will explicit instruction in scientific explanation and argumentation (experimental) improve student ability to write a formal laboratory report, over students instructed through traditionally-designed laboratories (control)? The null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student ability to write a formal laboratory report, failed to be rejected. The alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will improve student ability to write a formal written laboratory report, was rejected. There was not a statistically significant difference between experimental and control treatment groups adjusted mean scores for formal written laboratory reports (Figure 4.14, Table 4.5). Student participants submitted formal written laboratory reports after completion of the Week 9 photosynthesis experiment. At this time, students in the experimental group had submitted four written scientific explanations and arguments, which have similar components to formal written laboratory reports including writing hypotheses or claims, and supporting the claims with data or evidence and connecting the evidence to claim using reasoning. However, students in the experimental group did not have statistically higher scores on formal written laboratory reports than students in the control group, perhaps because students in
both the experimental and control groups were given handouts with detailed instructions on how to write a formal laboratory report.

**Student Perception of Biology as a Discipline of Science**

Will explicit instruction in scientific explanation and argumentation (experimental) influence student perception of biology as a discipline of science, compared to students instructed through traditionally-designed laboratories (control)?

The null hypothesis ($H_0$), which states: the treatment (experimental vs. control) will not affect student perception of biology as a discipline of science, was rejected. The alternative hypothesis ($H_A$), which states: the treatment (experimental vs. control) will affect student perception of biology as a discipline of science, failed to be rejected.

Students in the experimental treatment group had statistically significantly higher adjusted mean CLASS-bio posttest overall percent favorable scores than students in the control treatment group (Figure 4.17, Table 4.7). Therefore, students who received explicit instruction in scientific explanation and argument have more expert aligned opinions on their perception of biology as a discipline of science. Experts view science as a process to produce theories and explanations of natural phenomena based on empirical evidence, parsimony, and logic. Though theories, which are highly supported with empirical evidence, can be stable, explanations with less evidence are tentative and subject to change. Additionally, experts acknowledge that construction of scientific knowledge is influenced by culture, creativity, and ethical issues (AAAS, 1989, 1993; NRC, 2013; Saddler, 2004; Sandoval, 2003), while students tend to view science a collection of stable facts about the natural world (Nussbaum et al., 2008; Sandoval, 2003). Students who construct scientific explanations and arguments are learning to
construct scientific knowledge, an inquiry process that can influence their views on the nature of science (Bell & Linn, 2000; McNeill & Krajcik, 2008; Newton et al., 1999; Sandoval, 2003). This study’s findings for undergraduate students in a biology laboratory course are similar to findings at both the middle school and high school grade level classes looking at water quality and natural selection, which revealed students who constructed written scientific explanations and arguments gained more complex, scientist aligned views of the nature of science (Keys et al., 1999; Sandoval, 2003).

As students construct scientific explanations and arguments, they have the opportunity to experience how scientists or experts construct scientific knowledge allowing students to construct meanings for terms and scientific content used in the scientific explanation and argument (Berland & Reiser, 2009). As students and experts construct new knowledge, meanings are formed as connections are made between prior knowledge and new concepts, especially when overarching concepts become clear as is described as superordinate learning in Ausubel’s Cognitive Assimilation Theory for meaningful learning (Ausubel et al., 1978; Mintzes & Wandersee, 1998; Novak, 2010). Experts have a hierarchical organization of knowledge that allows them to see meaningful patterns of the knowledge in their domains that can be used when problem solving or constructing new knowledge (Bransford et al., 2000; Chi, Glaser, & Farr, 1988). Through construction scientific explanations and arguments, meanings are constructed, and perhaps the students’ knowledge structure becomes more hierarchical like an experts knowledge structure. A more hierarchical knowledge structure can help the student to understand how overarching concepts in science are developed, which is a more expert like view of the nature of science.
Objective 2

The second objective of this research study was to evaluate student progress of ability to write scientific explanations and arguments over the course of the semester. Students receiving explicit instruction in scientific explanation and argumentation wrote six explanations and arguments over the course of the semester. Will students’ ability to write scientific explanations and argument continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? The null hypothesis ($H_0$), which states: student ability to write scientific explanations and arguments will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), was rejected. The alternative hypothesis ($H_A$), which states: student ability to write scientific explanations and arguments will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), failed to be rejected. As discussed above in Objective 1: Student ability to construct written scientific explanations and arguments, explicit instruction improved student ability to construct written scientific explanations and arguments across grade levels and science domains (Lizotte et al., 2004; McNeill et al., 2009; Nussbaum et al., 2008; Stark et al., 2009; Zembal-Saul et al., 2002; Zohar & Nemet, 2002). Students had a mean score of 2.21±1.45 out of 12 for written scientific explanations and arguments on the pretest, which was given before students receive explicit instruction. Students earned statistically significantly higher scores on all following written scientific explanations and arguments collected over the course of the semester. Students earned the highest mean score of 9.88±1.25 out of 12 on the written scientific explanation and argument collected after the photosynthesis experiment, which was the fourth and last written scientific explanation.
and argument collected in class after completion of a laboratory activity or experiment. The score on photosynthesis experiment was statistically higher than all other collected written scientific explanations and arguments, except for the termite activity scientific explanation and argument, which was collected immediately after the initial explicit instruction on scientific explanation and argument, did not include quantitative data, and did not introduce new science content knowledge (Figure 4.18, Table 4.9). These results suggest that as students had more practice writing scientific explanations and arguments over the course of the semester, the quality of the written scientific explanations and arguments improved.

A similar pattern was seen when the six scientific explanations and arguments written by students, who received explicit instruction in scientific explanation and argumentation over the course of the semester, were broken down into four components: claim, evidence, reasoning, and counter argument. Each of the components of written scientific explanations and arguments is addressed below.

**Claim**

Will students’ ability to write claims in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? The null hypothesis ($H_0$), which states: student ability to write claims will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), was rejected. The alternative hypothesis ($H_A$), which states: student ability to write claims will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), failed to be rejected. Students’ ability to construct claims significantly increased after explicit instruction in scientific explanation
and argument. Students had a mean score of 1.41±0.87 out of 3 for claim on the pretest, which was given before students received explicit instruction. Students earned statistically significantly higher scores on all following claims collected over the course of the semester. Students earned the highest mean score of 2.97±0.18 out of 3 on the claim collected after the photosynthesis experiment, which was the fourth and last written scientific explanation and argument collected after completion of a laboratory activity or experiment during the semester. However, the photosynthesis experiment claim was not statistically significantly higher than the termite activity claim, the goldfish cellular respiration experiment claim, or the diffusion and osmosis experiment claim (Figure 4.19, Table 4.10). In McNeill and colleagues’ (2006) CER Framework, a claim is “an assertion or conclusion that answers a question” (p. 158). In order to make the CER Framework appropriate for undergraduate students, in this study a claim must also show a causal relationship between the independent variable and dependent variable. Though the claim component of the CER Framework was made more challenging for undergraduates students in this study, once students were instructed on what a claim was and given an example of a claim, students learned quickly how to construct an appropriate claim. Past research on difficulty constructing scientific explanations and arguments does not focus on difficulties of making a claim; rather it focuses on the difficulties of defending a claim using evidence, reasoning, and counter arguments or rebuttals (Bell & Linn, 2000; Berland & McNeill, 2010; Kuhn, 1991; McNeill et al., 2006; Saddler, 2004; Sandoval, 2003; Sandoval & Millwood, 2005).
Evidence

Will students’ ability to write evidence in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? The null hypothesis (H₀), which states: student ability to write evidence will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), was rejected. The alternative hypothesis (Hₐ), which states: student ability to write evidence will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), failed to be rejected. Students’ ability to include evidence statistically significantly increased after explicit instruction in scientific explanation and argument. Students had a mean score of 0.00±0.00 out of 3 for evidence on the pretest, which was given before students receive explicit instruction. Students earned statistically significantly higher scores for evidence on all other scientific explanations and arguments of all collected over the course of the semester. Students commonly use opinion instead of evidence and data to support a claim (Kuhn, 1991), but with explicit instruction, students can learn what is appropriate evidence and why data is necessary to support a claim in scientific explanations and arguments (Saddler, 2004; Sandoval & Millwood, 2005). In McNeill and colleagues’ (2006) CER Framework, evidence is “scientific data that supports the claim” (p. 158). Students earned the highest mean score of 2.91±0.28 out of 3 on the evidence included in the termite activity scientific explanation and argument, which only had qualitative evidence. However, the termite activity evidence was not statistically significantly higher than the diffusion and osmosis experiment evidence or the photosynthesis experiment evidence. The goldfish cellular respiration evidence score was significantly lower than termite activity, diffusion
and osmosis experiment, and photosynthesis experiment evidence scores (Figure 4.20, Table 4.11), perhaps because it was the first time students had quantitative data to include as evidence in their written scientific explanations and arguments, and students often fail to explicitly include data as evidence to support a claim (Sandoval, 2003).

**Reasoning**

Will students’ ability to include reasoning in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? The null hypothesis ($H_0$), which states: student ability to write reasoning will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), was rejected. The alternative hypothesis ($H_A$), which states: student ability to write reasoning will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), failed to be rejected. Students’ ability to include reasoning statistically significantly increased after explicit instruction in scientific explanation and argument, and continued to increase over the course of the semester. McNeill and colleagues’ (2006) CER Framework, reasoning is “justification of why data count as evidence to support a claim” (p. 158). Students had a mean score of $0.53 \pm 0.66$ out of 3 for reasoning on the pretest. Providing reasoning is one of the most challenging aspects of writing a scientific explanation and argument (Bell & Linn, 2000; Kuhn, 1991; Sandoval & Millwood, 2005); however, after explicit instruction, students earned statistically significantly higher scores for reasoning on all other scientific explanations and arguments of all collected over the course of the semester. Students earned the highest mean score of $2.68 \pm 0.47$ out of 3 on reasoning collected after the photosynthesis experiment, which was the fourth and last written scientific explanation
and argument collected in class after completion of a laboratory activity or experiment. The mean reasoning score on photosynthesis experiment was statistically significantly higher than all reasoning mean scores collected over the course of the semester, except for the goldfish cellular respiration experiment mean reasoning scores (Figure 4.21, Table 4.12), suggesting that the quality of student reasoning improved as students had more practice writing scientific explanations and arguments over the course of the semester. In order to discuss how evidence supports a claim, reasoning must include both logic and scientific principles (McNeill, 2009). Including scientific principals in reasoning a claim is especially challenging for students when they do not fully understand the principles (McNeill et al., 2006). This may explain the statistically significantly lower mean reasoning scores for the diffusion and osmosis experiment, which was the third the written scientific explanation and argument collected during week six after completion of a laboratory activity or experiment.

**Counter Argument**

Will students’ ability to write counter arguments in scientific explanations and arguments continuously increase during the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam)? The null hypothesis (H₀), which states: student ability to write counter arguments will not change over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), was rejected. The alternative hypothesis (Hₐ), which states: student ability to write counter arguments will change and perhaps increase over the course of the semester (from Pretest to Week 1, 2, 6, 9 to Final Exam), failed to be rejected. Students, ability to include a counter argument significantly increased after explicit instruction in scientific explanation and argument. Students had a mean score of
0.00 ± 0.00 out of 3 for counter argument on the pretest, which was statistically significantly lower than all other counter arguments collected over the course of the semester and collected before students received explicit instruction in scientific explanation and argument. Students earned the highest mean score of 1.44 ± 1.21 out of 3 on the termite activity counter argument. However, there was not a significant difference between mean counter argument scores on for the termite activity, goldfish cellular respiration experiment, diffusion and osmosis experiment, photosynthesis experiment, or the posttest (Figure 4.22, Table 4.13). Additionally, students earned the lower mean scores of the counter argument component of the modified CER Framework than for the claim, evidence and reasoning components (Figures 4.19 - 4.22, Tables 4.10 – 4.13), perhaps because when a counter argument or rebuttal is included, a scientific explanation and argument is considered to be more complex (Berland & McNeill, 2010). A counter argument or rebuttal “makes a claim about why alternative claims are incorrect and uses additional evidence and reasoning to justify that rationale” (Berland and McNeill, 2010, pp. 772-773), and students often have a difficult time coming up with alternative claims for data (Saddler, 2004).

**Objective 3**

The third objective was to understand how various demographic and academic variables can influence student ability to construct written scientific explanations and arguments. What demographic and academic variables positively influence student ability to construct scientific explanations and arguments? Using standard multiple regression, a statistically significant model to explain variation in student ability to write scientific explanations and arguments was produced. The treatment (students receiving
explicit instruction in scientific explanation and argumentation [experimental treatment] vs. students instructed through traditionally-designed laboratories [control treatment]), $\beta = -0.587, p = 0.00$, and posttest biological content knowledge percentage score, $\beta = 0.506, p = 0.00$, added significantly to the standard multiple regression model explaining variation in student ability to construct scientific explanations and arguments. As discussed above in Objective 1: Student ability to construct written scientific explanations and arguments and Objective 2, explicit instruction improves student ability to construct written scientific explanations and arguments across grade levels and science domains (Lizotte et al., 2004; McNeill & Krajcik., 2009; Nussbaum et al., 2008; Stark et al., 2009; Zembal-Saul et al., 2002; Zohar & Nemet, 2002). Therefore, it was reasonable that whether or not a student has had explicit instruction in scientific explanation and argument can be used to predict the quality of written scientific explanations and arguments. Student posttest biological content knowledge percentage scores can also be used to predict the quality of written scientific explanations and arguments. Students must use specific biological content knowledge to select evidence and use reasoning to support a given claim (Osborne et al., 2004). Therefore difficulty understanding content knowledge will make it more difficult for a student to construct a scientific explanation and argument (McNeill & Krajcik, 2009; McNeill et al., 2006; Metz, 2000; Saddler, 2004), and students who have a better understanding of content knowledge should be able to construct better scientific explanations and arguments. In this study students enrolled in an undergraduate introductory biology laboratory course who had higher scores on a biological content knowledge posttest were able to construct higher quality scientific explanations and arguments. Similar results were found where middle school students
completing a chemistry unit were able to write better scientific explanations and arguments for topics on which they had better scores on a multiple choice exam (McNeill et al., 2006).
CHAPTER 6.
CONCLUSIONS

This quantitative research study investigated the affects of explicit instruction on scientific explanation and argument in an undergraduate, introductory biology laboratory course using a modified version of McNeill and colleagues’ (2006) Claim, Evidence, and Reasoning Framework. Constructing written scientific explanations and scientific arguments plays an important roll in the process of science inquiry and science education (Duschl & Osborne, 2002; NRC, 1996; Newton, Driver, & Osborne, 1999; Sandoval & Millwood, 2005). Scientific explanations and scientific arguments are important aspects of science literacy and are addressed in science education literature including the National Science Education Standards [NSES] (NRC, 1996), A Framework for K-12 Science Education [A Framework] (NRC, 2012), and the Next Generation Science Standard: Public Release II [NGSS] (NRC, 2013). Unfortunately, construction of scientific explanations and scientific arguments is often excluded from classroom practices (Newton, Driver, & Osborne, 1999), perhaps because the construction of written scientific explanations and scientific arguments is a challenging and time-consuming process. Additionally, science teachers themselves may find construction of written scientific explanations and arguments challenging, which makes it difficult for them to teach. Individuals of all ages, including adults and undergraduate students have difficulty constructing written scientific explanations and arguments, especially coordinating claims and evidence through reasoning (Kuhn, 1991, Stark, 2005, Stark et al., 2009). This study further supports existing science education literature across grade levels and science domains that explicit instruction in scientific explanation and argument improves the quality of students’ written scientific explanations and arguments.
Additionally, the study demonstrated that the quality of written scientific explanations and arguments seems to improve with scaffolded practice over the course of the semester. Undergraduate introductory courses are often the last formal science education an individual receives (AAAS, 2011; PCAST, 2012), making them an ideal place to introduce this challenging process of science inquiry and promote science literacy.

Science content knowledge and understanding of the nature of science are important aspects of science literacy and associated with student construction of scientific explanations and arguments. Past research has indicated student construction of written scientific explanations and arguments can result in increased content knowledge understanding (Bell & Linn, 2000; Berland & Reiser, 2009; McNeill et al., 2006; Zohar & Nemet, 2002). This research study revealed there was not a difference in biological content knowledge scores for students who received explicit instruction and constructed written scientific explanations and arguments who were taught through traditionally-designed laboratories, therefore, including the time consuming activity of student construction of written scientific explanations and arguments did not take away from the level of content knowledge students gained. However, biological content knowledge was found to be an influencing variable when explaining variation in student ability to construct written scientific explanations and arguments, supporting the relationship between science content knowledge and construction of scientific explanations and arguments discussed in science education literature (McNeill & Krajcik, 2009; McNeill et al., 2006; Metz, 2000; Saddler, 2004). Student construction of scientific explanations and arguments has been shown to promote student understanding of the nature of science (Bell & Linn, 2000; Duschl & Osborne, 2002; Nussbaum et al. 2008). This study also
supported the idea that students who receive explicit instruction and write scientific
explanations and arguments have a more expert aligned view of biology as a discipline of
science and therefore a better understanding of the nature of science, which is an
important part of science laboratory courses where students are participating in science
inquiry.

The majority of research on scientific explanation and argument has focused on
K-12 science education and there is little research at the undergraduate level, especially
in introductory biology laboratory courses. However, this study has contributed to
science education literature providing insight into the role of explicit instruction of
scientific explanation and argument in undergraduate introductory biology laboratory
courses. This research study has shown that it is possible to incorporate construction of
written scientific explanations and arguments, using the college level appropriate
modified CER Framework (McNeill et al., 2006), to increase the level of inquiry of more
traditional “cookbook” laboratories that are so common in large regional universities,
without increasing the amount of class time.

**Future Research**

Data for this research study was collected over the course of the Fall 2013
semester during which the introductory biology laboratory course had fourteen class
meetings. Fourteen weeks is a fairly short amount of time for students to be engaged in
and learn a challenging science inquiry process like construction of written scientific
explanations and arguments. One way to further this research study is investigate the
affect of explicit instruction on student construction of written scientific explanations and
arguments over the length of two semesters by extending the study to include the second
introductory biology laboratory course, which covers evolution, ecology, and animal diversity.

Additionally, the researcher finds it interesting that the mean reasoning scores students earned on the diffusion and osmosis experiment were statistically significantly lower than the mean reasoning scores for the termite activity, the goldfish cellular respiration activity, and the photosynthesis activity. This study was only conducted over the course of one semester, and it would be interesting to see if continuing the study for an additional semester found similar results. If similar results were found, further research studies could reveal if and how various topics of science content knowledge affect student ability to construct written scientific explanations and arguments.
REFERENCES


Howard Hughes Medical Institute. (1998). *Beyond Biology 101.* Howard Hughes Medical Institute, Chevy Chase, MD.


National Science Board. (1986). *Undergraduate science, mathematics and engineering education*. National Science Foundation, Washington, DC.


## APPENDIX 1.
### SCIENTIFIC EXPLANATION AND ARGUMENT BASE RUBRIC

<table>
<thead>
<tr>
<th></th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
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</thead>
<tbody>
<tr>
<td><strong>Claim</strong></td>
<td>Answers question. Includes causal relationship between independent and dependent variables.</td>
<td>Answers question. Includes independent or dependent variables, but does not show causal relationship.</td>
<td>Answers question. Does not include independent or dependent variables.</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>Quantitative and Qualitative data included in scientific argument. Data collected is directly associated with dependent variable. All relevant data are used as evidence to support claim.</td>
<td>Data included associated with variables, but not all relevant data included as evidence.</td>
<td>Data included not associated with variables.</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Reasoning follows logically. Steps in reasoning are made explicit and do not jump quickly to claim. Uses appropriate scientific principles</td>
<td>Reasoning follows logically and steps in reasoning are made explicit, but scientific principles are not used.</td>
<td>Reasoning jumps from evidence to claim but not sufficiently explained.</td>
</tr>
<tr>
<td><strong>Counter Argument</strong></td>
<td>States counter claim. Shows how evidence best supports claim rather than counter claim. Reasoning follows logically.</td>
<td>Counter claim included but lacks evidence or reasoning to support claim instead of counter claim.</td>
<td>Counter claim included but lacks evidence and reasoning to support claim instead of counter claim.</td>
</tr>
</tbody>
</table>

Modified from (McNeill, Lizotte, Krajcik, & Marx, 2006)
APPENDIX 2.
CONTENT KNOWLEDGE PRETEST

The content knowledge pretest for the undergraduate introductory biology laboratory has been modified from the departmental exam given to students attempting to test out of introductory biology laboratory and lecture.

1. Which of the following does not belong within this group?
   a. insulin  b. glycogen  c. collagen  d. keratin  e. both a and b

2. When you get a tooth pulled it leaves a big hole in your mouth. Eventually, that hole closes. How does that hole close?
   a. haploid cells produce new diploid cells  b. mitosis helps produce new cells
   c. meiosis produces new cells to close the hole  d. interphase produces new cells

3. Excess glucose is stored in your liver and muscle tissue as a polymer known as glycogen. Through what process are these glucose molecules linked together to form this polymer?
   a. hydrolysis reactions  b. photolysis
   c. dehydration synthesis reactions (condensation)
   d. phosphodiester linkage  e. both a and c

4. Enzymes accelerate chemical reactions by ____.
   a. burning glucose in stages  b. increasing the potential energy of the reaction
   c. deleting the action potential  d. decreasing the amount of activation energy

5. What is carbon fixation and when does it occur?
   a. conversion of CO₂ into ATP during dark reactions
   b. conversion of CO₂ into ATP during light reactions
   c. conversion of CO₂ into organic molecules during the light dependent reactions (1st stage of photosynthesis)
   d. conversion of CO₂ into organic molecules during the light independent reactions (2nd stage of photosynthesis)

6. Specifically, what is responsible for trapping light energy in plants?
   a. stroma  b. chlorophyll  c. vascular bundles  d. stomata  e. veins
7. How is breathing associated with glucose catabolism?
   a. we exhale CO$_2$ that is produced by the transition reaction and Kreb’s cycle
   b. we inhale oxygen that is produced by the Kreb’s cycle
   c. we inhale O$_2$ that enables aerobic metabolism
   d. both a and c

8. Explain the results of this cross regarding the trait for attached earlobes.

   A = unattached (free)  a = attached

   Parents:  Aa  x  aa

<table>
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<tr>
<th>Aa</th>
<th>aa</th>
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<tbody>
<tr>
<td>Aa</td>
<td>aa</td>
</tr>
</tbody>
</table>

   a. these parents produced 2 offspring with earlobes
   b. if these parents reproduce they have a 50% chance of having a child with attached earlobes
   c. if these parents reproduce they could have 3 offspring without earlobes
   d. if these parents reproduce they have a 0% chance of having a child with attached earlobes

9. In a Mendelian dihybrid cross, if one parent contains Bbrr in its diploid cells what gene combinations could be found in that parent’s normal sex cells?

   a. Br, br, br, BR  b. BR, bb, br, br  
   c. BR, br, br, br
   d. Br, Br, br, br  e. Br, Br, bb, rr

10. Which of the following may lead to genetic variation (diversity) in a life cycle?
    a. Telophase  b. Metaphase I  c. cytokinesis
    d. random fertilization  e. both b and d

11. A major characteristic that distinguishes meiosis from mitosis is ____.
    a. only one division of DNA during meiosis  b. the absence of prophase in mitosis.
    c. chromosomes condense during prophase  d. meiosis reduces chromosome number

12. The main function of meiosis is ____.
    a. maintenance  b. growth  c. sex cell production  d. cell repair e. both a and b
13. Do most plants use aerobic respiration to break down food to provide their cells with energy? If not, what do they do?
   a. Yes    b. No, they only need to photosynthesize
   c. No, they use photorespiration    d. b and c

Use the diagram below to answer questions 14-15.

14. What will happen to the cell given the above situation? Remember, the cell has a selectively permeable membrane.
   a. swell    b. shrink    c. nothing    d. burst    e. both a and d

15. In reference to the previous question, what is the main process in action?
   a. facilitated diffusion    b. osmosis    c. active transport    d. glucose pump

16. Why is water so important to plants?
   a. turgor pressure    b. prevent wilting
   c. provides hydrogens for photosynthesis as NADPH
   d. all are correct    e. none are correct

17. Aerobic respiration occurs in eukaryotic cell organelles called ____?
   a. Golgi bodies    b. endoplasmic reticulum    c. mitochondria    d. cytosol

18. How many CO₂ molecules are required to produce 1 molecule of glucose in the C3 cycle?
   a. 3 b. 6    c. 5    d. 1    e. 2

19. A healthy potato plant may use the glucose it produced during photosynthesis to ___?
   a. store as starch    b. produce oxygen
   c. grow and make big potatoes    d. a and c are correct
20. What is in a nucleus?
   a. mitochondria   b. DNA   c. cytoplasm
   d. Rough E.R.   e. both a and c

21. Since muscle cells work very hard they contain a much higher number of this organelle than most cells do.
   a. vesicles   b. golgi complex   c. rough ER   d. mitochondria   e. nuclei

22. Why does sugar dissolve faster in hot tea rather than in iced tea?
   a. osmosis slows down
   b. diffusion of molecules increases as temperature increases
   c. change in temperature causes a change in pH
   d. diffusion of tea decreases and diffusion of sugar decreases

23. What would be the complementary strand of DNA, given one strand looks like this GCATTAGTC?
   a. GCATTAGTC   b. CGTAATCAG   c. CGUAAUCAG   d. CTGATTACG

24. Which of the following is not true of RNA?
   a. nucleic acid   b. single stranded
   c. translates DNA into proteins   d. only found in the nucleus

25. _____ are large organic molecules made from numerous repeating similar subunits
   a. monomers   b. polymers   c. isomers   d. fatty acids   e. oils

26. What is the **main thing** that a cell must do in order to make an exact copy of itself?
   a. undergo meiosis and mitosis   b. divide its cytoplasm
   c. copy its organelles   d. copy its DNA

27. Which of the following are true of chromosomes?
   a. made from DNA and protein   b. contain genes
   c. visible during cell division   d. all are true   e. both a and b only
Use this scenario to answer questions 28-30.

Justin the **Pine tree** farmer is trying to decide if he should change fertilizers, he is currently using “Triple 13” inorganic fertilizer. He conducted an experiment to test which fertilizer promotes tree growth best. Therefore, Justin fertilized 20 trees with cow manure, 20 with “Super Green” tree fertilizer, and 20 with regular “Triple 13” inorganic fertilizer. Justin measured initial and final height growth of the trees over a 3-year period.

28. What is the dependent variable in the experiment above?
   
a. Cow manure  
b. fertilizer type  
c. Pine trees  
d. height growth  
e. both a and b

29. The best null hypothesis for the above example is ____?
   
a. Cow manure fertilizer will increase height growth of trees.
   
b. Fertilizer type does affect plant growth.
   
c. Super Green fertilizer is the best.
   
d. The type of fertilizer used will have no affect on the growth of pine trees.

30. Using the above scenario concerning Justin’s experiment, and the data provided, write a scientific explanation and supporting argument on your answer sheet that answers the following question: “What fertilizer should Justin use on his pine tree farm?.” (Hint: What (if any) other factors might Justin want to consider?)
APPENDIX 3.
LABORATORY REPORT RUBRIC

Analysis of Laboratory Report

Title  2pts
□ Original and descriptive
□ Your name and your partners’

Introduction  12pts
□ □ Purpose of experiment
□ □ □ Background information
□ □ □ References in text
□ □ Null hypothesis, variables

Materials and Methods  6pts
□ □ Describe M and M
□ Do not list
□ □ □ Describe experimental setup

Results  5pts
□ □ □ Describe trends in data
□ Do not explain
□ Refer to graph

Graph  7pts
□ □ □ Axes labeled w/ units
□ Proper format
□ Must be large and readable
□ Figure legend

Discussion  10pts
□ □ Accept/Reject Null hypothesis, Claim
□ □ □ Explain why, Interpret data
□ □ □ Reasoning
□ Possible Error
□ Extension

Literature Cited  3pts
□ □ □ Three quality references

Grammar and Formatting  5 pts
□ □ □ □ □

Comments: ____________________________

Total Score: _________ / 50pt
APPENDIX 4.
THE COLORADO LEARNING ATTITUDES ABOUT SCIENCE SURVEY FOR USE IN BIOLOGY COURSES STUDENT DIRECTIONS AND STATEMENTS

Here are a number of statements that may or may not describe your beliefs about learning biology. You are asked to rate each statement by selecting a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Circle one of the above five choices that best expresses your feeling about the statement on the answer sheet provided. If you don't understand a statement, leave it blank. If you have no strong opinion, choose 3.

We are asking that you express your own beliefs. Your answers will not affect your grade. This information will be very helpful to us in an effort to design more effective biology courses.

Survey (8-10 minutes)

1. My curiosity about the living world led me to study biology

2. I think about the biology I experience in everyday life.

3. After I study a topic in biology and feel that I understand it, I have difficulty applying that information to answer questions on the same topic.

4. Knowledge in biology consists of many disconnected topics.

5. When I am answering a biology question, I find it difficult to put what I know into my own words.

6. I do not expect the rules of biological principles to help my understanding of the ideas.

7. To understand biology, I sometimes think about my personal experiences and relate them to the topic being analyzed.
8. If I get stuck on answering a biology question on my first try, I usually try to figure out a different way that works.

9. I want to study biology because I want to make a contribution to society.

10. If I don’t remember a particular approach needed for a question on an exam, there’s nothing much I can do (legally!) to come up with it.

11. If I want to apply a method or idea used for understanding one biological problem to another problem, the problems must involve very similar situations.

12. I enjoy figuring out answers to biology questions.

13. It is important for the government to approve new scientific ideas before they can be widely accepted.

14. Learning biology changes my ideas about how the natural world works.

15. To learn biology, I only need to memorize facts and definitions.

16. Reasoning skills used to understand biology can be helpful to my everyday life.

17. It is a valuable use of my time to study the fundamental experiments behind biological ideas.

18. If I had plenty of time, I would take a biology class outside of my major requirements just for fun.

19. The subject of biology has little relation to what I experience in the real world.

20. There are times I think about or solve a biology question in more than one way to help my understanding.

21. If I get stuck on a biology question, there is no chance I'll figure it out on my own.

22. When studying biology, I relate the important information to what I already know rather than just memorizing it the way it is presented.
23. There is usually only one correct approach to solving a biology problem.

24. When I am not pressed for time, I will continue to work on a biology problem until I understand why something works the way it does.

25. Learning biology that is not directly relevant to or applicable to human health is not worth my time.

26. Mathematical skills are important for understanding biology.

27. I enjoy explaining biological ideas that I learn about to my friends.

28. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.

29. The general public misunderstands many biological ideas.

30. I do not spend more than a few minutes stuck on a biology question before giving up or seeking help from someone else.

31. Biological principles are just to be memorized.

32. For me, biology is primarily about learning known facts as opposed to investigating the unknown.
APPENDIX 5.
STUDENT DEMOGRAPHIC AND ACADEMIC SURVEY ITEMS

1. Year in School: ______
2. Age: ______
3. Gender: (Male/Female)
4. Race: (select the one with which you most identify: Caucasian/White; African America; Native American; Asian; Hispanic; Pacific Islander; other: ____________ )
5. Father’s Level of Education: (circle one: less than High School Diploma; GED; High School Diploma; Associates Degree; Bachelors Degree; Masters Degree; Doctoral or Medical Degree)
6. Mother’s Level of Education: (circle one: less than High School Diploma; GED; High School Diploma; Associates Degree; Bachelors Degree; Masters Degree; Doctoral or Medical Degree)
7. What High School did you graduate from? (Name, City, State) ____________________
_____________________________________________________________________
8. High School Grade Point Average: ______
9. High School Science Grade Point Average (circle one: mostly As; mostly As & Bs; mostly Bs; Cs & above; Cs & below)
10. Number of Science Courses Taken in High School. _____ Please list: _____________
_____________________________________________________________________
11. Did you take Advance Placement (AP), Dual Enrollment (college credit), or honors courses in high school? If yes, which:_____ If yes, please list courses:_____________
_____________________________________________________________________
12. ACT Score: ______
13. Current Major: ______
14. Do you plan to change your major?_____ If yes, please list: ____________________

15. Currently, what is your level of interest in biology (Very Low; Low; Moderate; High; Very High)? Why?
16. Do your future plans include ... (biology related grad school; medical school; pursue a 
career in the medical field, but not medical school; teaching K-12 science; pharmacy 
school; Other, please specify)?

17. I ... agree ... do not agree ... (circle one) ... to permit the investigators to obtain and 
use my academic history, course grades, attendance records, and GPA for this research to 
 improve this and other courses in science. This information will be seen only by the 
researchers. Identifying information (name, ID) will only be used to combine these 
survey answers and the coursework data and will be deleted prior to any subsequent 
analysis.

By submitting this paper you are agreeing to participate in this research project as 
outlined in the "Informed Consent Document" above.

If you do not want to participate, simply do not answer the questions and submit only 
your name and ID.

We thank you for taking the time to fill out this survey. Your participation is really 
helpful because knowing more about students' beliefs about biology helps improve our 
teaching practices.
## APPENDIX 6.
### SCIENTIFIC EXPLANATION AND ARGUMENT PRETEST RUBRIC

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<tbody>
<tr>
<td><strong>Claim</strong></td>
<td>Answers: What fertilizer should Justin use at his pine tree farm? Includes causal relationship between independent (type of fertilizer) and dependent variable (pine tree height growth).</td>
<td>Answers Question: What fertilizer should Justin use at his pine tree farm? Includes independent (type of fertilizer) and dependent variable (pine tree height growth), but does not show causal relationship</td>
<td>Answers Question: What fertilizer should Justin use at his pine tree farm? Does not include independent (type of fertilizer) or dependent variable (pine tree height growth).</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>Qualitative data included in scientific argument (pine tree height growth included for CM, SG, and T13). Data collected is directly associated with dependent variable (pine tree height growth is recorded with units (cm)).</td>
<td>Qualitative data included in scientific argument, but incomplete. Does not discuss CM, SG, and T13. Failure to include units (cm)</td>
<td>Data included not associated with dependent variable (not specifically pine tree height growth).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that fertilizers CM and SG result in a greater amount of pine tree height growth, than T13. Includes Scientific principle: NA</td>
<td>Explicitly writes that fertilizers CM and SG result in a greater amount of pine tree height growth.</td>
<td>Reasoning jumps from evidence to claim, but is not sufficiently explained. It is not explicitly stated how one learned the pine tree height growth is affected by fertilizer.</td>
</tr>
<tr>
<td><strong>CounterArgument</strong></td>
<td>Counterclaim included; evidence is used to support claim instead of counter claim. Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim included.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. OR Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. AND Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
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### APPENDIX 7.
### SCIENTIFIC EXPLANATION AND ARGUMENT TERMITE ACTIVITY RUBRIC

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<tr>
<td><strong>Claim</strong></td>
<td>Answers: Why is the termite behaving in this manner? Includes causal relationship between independent (Smell of Papermate ink) and dependent variable (Termites’ behavior).</td>
<td>Answers Question: Why is the termite behaving in this manner? Includes independent (smell of Papermate ink) and dependent variable (Termites’ behavior), but does not show causal relationship</td>
<td>Answers Question: Why is the termite behaving in this manner? Does not include independent (smell of Papermate ink) or dependent variable (Termites’ behavior).</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>Qualitative data included in scientific argument (Termite follows blue Papermate ink path, but will not follow other paths, pencil, marker, or gel pen). Data collected is directly associated with dependent variable (following path is observed behavior of termite).</td>
<td>Qualitative data included in scientific argument, but failure to include that termite follows Papermate ink path AND does not follow pencil, marker, or gel pen path.</td>
<td>Data included not associated with dependent variable (termite’s behavior).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that termites will follow ink path, but will not follow other paths. Therefore termite is following the smell of the Papermate ink or substance associated with the ink. Includes Scientific principle: pheromones and ink</td>
<td>Explicitly writes that termites will follow ink path, but will not follow other paths. Therefore termite is following the smell of the Papermate ink or substance associated with the ink. Does not include scientific principle.</td>
<td>Reasoning jumps from evidence to claim, but is not sufficiently explained. It is not explicitly stated how one learned the termites’ behavior is influenced by smell of Papermate Ink.</td>
</tr>
<tr>
<td><strong>Counter Argument</strong></td>
<td>Color of path does not affect termites’ behavior. Discusses explicitly that when same pen, but different color is used, termite will follow the path, therefore color of the path must not influence the termite.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. OR Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. AND Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
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<tr>
<td><strong>Claim</strong></td>
<td>Answers Question: How do goldfish deal with cold water temperature? Includes causal relationship between and both the independent variable (water temp.) and dependent variable (goldfish respiration rate).</td>
<td>Answers Question: How do goldfish deal with cold water temperature? Causal relationship between the independent and dependent variables is unclear, and the independent variable OR the dependent variable is unclear.</td>
<td>Answers Question: How do goldfish deal with cold water temperature? Does not include causal relationship of the variable or include the independent variable (water temp.) and dependent variable (goldfish respiration rate).</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>All potential quantitative data included in scientific argument. Both group data and class averages of goldfish respiration rate at a given water temperature reported. Data is directly associated with dependent variable and units are reported as breaths per minute and °C.</td>
<td>Failure to include all potential data (Did NOT report: Group data, Class Average). Failure to report temperature at which respiration rate is collected. Failure to include units: °C and/or breaths per minute</td>
<td>Data included not associated with dependent variable (goldfish respiration rate: breaths per minute).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that data support that as the water temperature decreases, the breaths per minute of the fish decreases. Uses appropriate scientific principles by drawing connection between breathing rate of the fish and energy production: cellular respiration).</td>
<td>Explicitly writes that data support that as the water temperature decreases, the breathing rate of the fish decreases. Failure to include appropriate scientific principles, OR includes scientific principles, but uses them incorrectly/lacks understanding.</td>
<td>Reasoning jumps from evidence (the breathing rate of the fish at various water temperatures) to claim but not sufficiently explained. Does not explicitly draw conclusion from evidence.</td>
</tr>
<tr>
<td><strong>Counter Argument</strong></td>
<td>Counter claim and rebuttal included with evidence and reasoning. Discusses that the control fish, which remained at a constant water temperature 22°, had a fairly constant respiration rate. Explicitly states that if it was not the water temp, that was affecting respiration rate, you should see a decreasing trend in the control fish respiration rate.</td>
<td>Counter claim and rebuttal for Water temperature does not affect goldfish respiration rate. Lacking evidence OR explicit reasoning in the rebuttal.</td>
<td>Counterclaim included but evidence is not used in a rebuttal to support claim instead of counter claim AND no explicit reasoning is included to support claim instead of counter claim.</td>
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APPENDIX 9.
SCIENTIFIC EXPLANATION AND ARGUMENT DIFFUSION AND OSMOSIS EXPERIMENT RUBRIC

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<tr>
<td><strong>Claim</strong></td>
<td>Answers Question: Why are the bags changing weight at different rates? Includes causal relationship between and both the independent variable (concentration gradient) and dependent variable [rate of osmosis as measured in weight change (g)].</td>
<td>Answers Question: What is causing the “cells” to gain or lose weight at different rates? Causal relationship between the independent and dependent variables is unclear, OR the independent variable OR the dependent variable is unclear.</td>
<td>Answers Question What is causing the “cells” to gain or lose weight at different rates? Does not include causal relationship of the variable and fails to include the independent variable (concentration gradient) OR dependent variable [weight change (g)].</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>All potential quantitative data included in scientific argument. Group data for 4 bags including concentration gradients and weight change included. Data is directly associated with dependent variable and units are reported in grams.</td>
<td>Failure to include all potential data (Did NOT report: concentration gradients, Bags 1, 2, 3, &amp; 4). Failure to include units: grams.</td>
<td>Data included not associated with dependent variable (weight change in grams).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that data support as the concentration gradient between the bag and surrounding solution increases, the weight change becomes more rapid. Uses appropriate scientific principles by drawing connection between weight change and osmosis, which is affected by concentration gradient).</td>
<td>Explicitly writes that data support as the concentration gradient between the bag and surrounding solution increases, the weight change becomes more rapid. Failure to include appropriate scientific principles (does not connect weight change to rate of osmosis), OR includes scientific principles, but uses them incorrectly/lacks understanding.</td>
<td>Reasoning jumps from evidence [the weight change (g) in bag] to claim but not sufficiently explained. Does not explicitly draw conclusion from evidence.</td>
</tr>
<tr>
<td><strong>Counter Argument</strong></td>
<td>Counter claim and rebuttal included with evidence and reasoning. Possible Counter Argument: The type of solution the bag is placed affects the weight change (g) of the bag. Explicitly states that both Bags 3 and 4 have a concentration gradient of 50, and Bag 3 gains as much weight at Bag 4 loses. Possible Counter Argument: Weight change is the result of sugar moving by diffusion, not osmosis. Explicitly discusses if this is the case, Bags 2 &amp;3 should lose weight, while Bag 4 should gain weight.</td>
<td>There are a number of possible counter arguments that could be included and rebutted. Counter claim included, but lacking evidence [failure to include Concentration Gradient and weight change (g) for Bags 3 &amp; 4] OR explicit reasoning in the rebuttal.</td>
<td>Counterclaim included but evidence is not used in a rebuttal to support claim instead of counter claim AND no explicit reasoning is included to support claim instead of counter claim.</td>
</tr>
</tbody>
</table>
## APPENDIX 10.
**SCIENTIFIC EXPLANATION AND ARGUMENT PHOTOSYNTHESIS EXPERIMENT RUBRIC**

<table>
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<tbody>
<tr>
<td><strong>Claim</strong></td>
<td>Answers Question: How does light intensity affect the rate of photosynthesis? Includes causal relationship between and both the independent variable (light intensity) and dependent variable [rate of photosynthesis as measured in oxygen produced (mm or mm³)].</td>
<td>Answers Question: How does light intensity affect the rate of photosynthesis? Causal relationship between the independent and dependent variables is unclear, OR the independent variable OR the dependent variable is unclear [rate of photosynthesis as measured in oxygen produced (mm or mm³)].</td>
<td>Answers Question: How does light intensity affect the rate of photosynthesis? Does not include causal relationship of the variable and fails to include the independent variable (light intensity) OR dependent variable [rate of photosynthesis as measured in oxygen produced (mm or mm³)].</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>All potential quantitative data included in scientific argument. Group data for amount of oxygen produced for both high light intensity and low light intensity. Data is directly associated with dependent variable and units are reported in (mm or mm³).</td>
<td>Failure to include all potential data (Did NOT report: light intensity, did not include oxygen produced at both high and low light intensity. Failure to include units: (mm or mm³)).</td>
<td>Data included not associated with dependent variable (oxygen produced through photosynthesis).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that data support as the light intensity increases, the amount of oxygen produced (mm or mm³) increases. Uses appropriate scientific principles by drawing connection between oxygen produced and photosynthesis, during photosynthesis, oxygen is released from the water molecule.</td>
<td>Explicitly writes that data support as the light intensity increases, the amount of oxygen produced (mm or mm³) increases. Failure to include appropriate scientific principles (does not connect between oxygen produced and photosynthesis, specifically photolysis), OR includes scientific principles, but uses them incorrectly/lacks understanding.</td>
<td>Reasoning jumps from evidence [oxygen produced] to claim but not sufficiently explained. Does not explicitly draw conclusion from evidence. Does not discuss as the light intensity increases, the amount of oxygen produced (mm or mm³), which is the rate of photosynthesis increases.</td>
</tr>
<tr>
<td><strong>Counter</strong></td>
<td>Counter claim and rebuttal included with evidence and reasoning. Possible Counter Argument: The forward movement of the bubble is a result of carbon dioxide or heat. Explicitly states that a control was set up to measure movement as a result of CO2 and heat, therefore by subtracting the control from the experimental we measuring forward movement from oxygen production.</td>
<td>There are a number of possible counter arguments that could be included and rebutted. Counter claim included, but lacking evidence [failure to discuss the control and that we subtracted forward movement of control from the experimental] OR explicit reasoning in the rebuttal.</td>
<td>Counterclaim included but evidence is not used in a rebuttal to support claim instead of counter claim AND no explicit reasoning is included to support claim instead of counter claim.</td>
</tr>
</tbody>
</table>
APPENDIX 11.
SCIENTIFIC EXPLANATION AND ARGUMENT POSTTEST GENETICS RUBRIC

<table>
<thead>
<tr>
<th>Claim</th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answers: Is George the child of Mr. &amp; Mrs. Green? Includes causal relationship between independent (parent geno/phenotype) and dependent variable (Childs geno/phenotype).</td>
<td>Answers Question: Is George the child of Mr. &amp; Mrs. Green? Includes independent (parent g/p) and dependent variable (child g/p), but does not show causal relationship</td>
<td>Answers Question: Is George the child of Mr. &amp; Mrs. Green? Does not include independent (parent geno:phenotype) or dependent variable (child geno:phenotype).</td>
<td></td>
</tr>
<tr>
<td>Evidence</td>
<td>Qualitative data included in scientific argument (Mr. &amp; Mrs. Green both Tt) collected is directly associated with dependent variable (offspring phenotype ratio 3 can roll tongue; 1 can not roll tongue)</td>
<td>Qualitative data included in scientific argument, but incomplete. Does not discuss genotype of both parents and all possible offspring genotypes and phenotypes</td>
<td>Data included not associated with dependent variable (ratio of possible offspring phenotypes are not discussed).</td>
</tr>
<tr>
<td>Reasoning</td>
<td>Explicitly writes that there is a 1 in 4 chance for two heterozygous parents with the ability to roll their tongue can produce an offspring that is homozygous recessive and cannot roll his tongue</td>
<td>Writes that parents with the ability to roll their tongue can produce an offspring that cannot roll his tongue, failure to discuss genotype and phenotype</td>
<td>Reasoning jumps from evidence to claim, but is not sufficiently explained. It is not explicitly stated how parents who can roll their tongue can produce offspring who can not.</td>
</tr>
<tr>
<td>Counter Argument</td>
<td>Counterclaim included (one parent is homozygous dominant); evidence is used to support claim instead of counter claim. Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim included.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. OR Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
<td>Counterclaim included but evidence is not used to support claim instead of counter claim. AND Explicit reasoning as to why the suggested evidence best supports claim instead of counter claim is not included.</td>
</tr>
</tbody>
</table>
**APPENDIX 12.**  
**SCIENTIFIC EXPLANATION AND ARGUMENT POSTTEST PHOTOSYNTHESIS RUBRIC**

<table>
<thead>
<tr>
<th></th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Claim</strong></td>
<td>Answers Question: How does light color affect the rate of photosynthesis? Includes causal relationship between and both the independent variable (light color) and dependent variable [rate of photosynthesis as measured in oxygen produced (mm or mm$^3$)].</td>
<td>Answers Question: How does light color affect the rate of photosynthesis? Causal relationship between the independent and dependent variables is unclear, OR the independent variable OR the dependent variable is unclear [rate of photosynthesis as measured in oxygen produced (mm or mm$^3$)].</td>
<td>Answers Question: How does light intensity affect the rate of photosynthesis? Does not include causal relationship of the variable and fails to include the independent variable (light color) OR dependent variable [rate of photosynthesis as measured in oxygen produced (mm or mm$^3$)].</td>
</tr>
<tr>
<td><strong>Evidence</strong></td>
<td>All potential quantitative data included in scientific argument. Group data for amount of oxygen produced for both red light and green light intensity. Data is directly associated with dependent variable and units are reported in (mm or mm$^3$).</td>
<td>Failure to include all potential data (Did NOT report: light color, did not include oxygen produced with both red and green light. Failure to include units: (mm or mm$^3$).</td>
<td>Data included not associated with dependent variable (oxygen produced through photosynthesis).</td>
</tr>
<tr>
<td><strong>Reasoning</strong></td>
<td>Explicitly writes that data support red light produces a higher amount of oxygen (mm or mm$^3$) than green light. Uses appropriate scientific principles by drawing connection between oxygen produced and photosynthesis, during photolysis, oxygen is released from the water molecule. Green light is reflected not absorbed by the chlorophyll; therefore with red light photosynthesis can occur at a higher rate.</td>
<td>Explicitly writes that data support red light produces a higher amount of oxygen (mm or mm$^3$) than green light. Failure to include appropriate scientific principles (does not connect between oxygen produced and photosynthesis, specifically photolysis; does not acknowledge green light is reflected not absorbed), OR includes scientific principles, but uses them incorrectly/lacks understanding.</td>
<td>Reasoning jumps from evidence [oxygen produced] to claim but not sufficiently explained. Does not explicitly draw conclusion from evidence. Does not discuss the colors or light affect, the amount of oxygen produced (mm or mm$^3$), which is the rate of photosynthesis increases, because green light is reflected and not absorbed.</td>
</tr>
<tr>
<td><strong>Counter Argument</strong></td>
<td>Counter claim and rebuttal included with evidence and reasoning. Possible Counter Argument: The forward movement of the bubble is a result of carbon dioxide or heat. Explicitly states that a control was set up to measure movement as a result of CO2 from solution and heat from lamp, therefore by subtracting the control from the experimental we measuring forward movement from oxygen production.</td>
<td>There are a number of possible counter arguments that could be included and rebutted. Counter claim included, but lacking evidence [failure to discuss the control and that we subtracted forward movement of control from the experimental] OR explicit reasoning in the rebuttal.</td>
<td>Counterclaim included but evidence is not used in a rebuttal to support claim instead of counter claim AND no explicit reasoning is included to support claim instead of counter claim.</td>
</tr>
</tbody>
</table>
## APPENDIX 13.
### INTRODUCTION TO SCIENCE AND BIOLOGY:
#### TERMITE ACTIVITY LESSON PLAN

<table>
<thead>
<tr>
<th>Experimental Treatment</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives:</strong> Students should</td>
<td><strong>Objectives:</strong> Students should</td>
</tr>
<tr>
<td>1. understand what is science</td>
<td>1. understand what is science</td>
</tr>
<tr>
<td>2. understand the concepts of scientific explanation and argument and its components</td>
<td>2. understand the concept of the scientific method and its components</td>
</tr>
<tr>
<td>3. know the component s of experimental design</td>
<td>3. know the component s of experimental design</td>
</tr>
<tr>
<td>4. apply science, scientific explanation and argument, and experimental design to the termite activity</td>
<td>4. apply science, scientific method, and experimental design to the termite activity</td>
</tr>
</tbody>
</table>

**Class Discussion: What is Science?**
1. Attempts to explain natural phenomena
   a. Based on natural laws of physics and chemistry
   b. consistent with currently accepted scientific principles
2. Based off logic, observation, and evidence
3. Topics must be testable, no supernatural explanations.
4. Self corrects, old ideas give way to new ideas; tentative conclusions: if there is new evidence which contradicts old ideas, the ideas need to be modified.

**Students are introduced to:**

**Scientific Explanation and Argument**
1. Importance of explanation and argument in science.
2. **Scientific Explanations:** statements that attempt to make sense of observations of natural phenomena
   a. products of science
   b. broad or limited scope
   c. a hypothesis is a type of explanation
   d. a theory is a type of explanation
3. **Scientific Arguments:** used to develop and justify scientific explanations of natural phenomena
   a. use logic and reasoning to connect evidence with the conclusions drawn
   b. evidence by observation and experimentation

**Students are introduced to:**

**The Scientific Method**
1. Observation
2. Form Hypothesis
3. Test Hypothesis
   a. Experiment or more observation
   b. Collect data
4. Interpret results
5. Form Conclusions
   a. Theories are highly supported by many observations and experiments and are retained until there is valid evidence the theory is false
**Experimental Design**

- **Variables**
  - Independent variable: the variable the biologist manipulates
  - Dependent variable: the result/response of the independent variable
- Null Hypothesis: IV does not affect the DV; no interaction between variables.
- Alternative hypothesis: IV does affect the DV;
- Control: baseline for comparison, to show that results are a result of the treatment, rather than an external factor
- Replication: always perform experiment more than once same results from repeated trials increases confidence that results are correct.

(As components of experimental design are introduced, the Ant-B-Gone example in the laboratory manual is used (White & Campo, 2013, pp3-4))

Students are given a copy of the scientific explanation and argument base rubric (see Appendix 1).

**Introduction of the modified Claim, Evidence, and Reasoning Framework (McNeill et al., 2006)**

- Include: explicit definitions and rationale for each component.
- Model using Ant-B-Gone example

Claim: an assertion or conclusion that answers a question (scientific explanation)

- Goal of science is to attempt to explain natural phenomena

Evidence: scientific data that supports the claim (quantitative and qualitative)

- Collected through observation or experimenting

Reasoning: justification of why data count as evidence to support a claim

- Logic and scientific principles that work to show how evidence is linked to and support the claim

Counter Argument: another explanation or claim that may answer the question, and why evidence and reasoning do not support this claim.

- Your claim is stronger when you can show the data support it better than another claim
Termite Activity

Materials: Blank scratch paper, blue and black Papermate pens and pencils, termites

1. Draw a circle approx. 5” in diameter with the blue Papermate pen.

2. Gently shake 2-3 termites on your scratch paper.

3. Gently herd them into the circle with the artist brushes then leave them alone.

4. Observe the termites’ behavior

5. Why are they behaving in such a manner?

6. Students must define what behavior they are looking for. To consider the termites following the lines they must follow consistently.

7. Work within your group for 5-10 min and generate at least 3 hypotheses. (Make sure they are writing hypotheses as you demonstrated earlier in your example experiment)

8. Students to volunteer their hypotheses. Write at least three on the board. Remind them these should be Null hypotheses. (Leave room for writing alternative hypotheses under each null on board.)

9. Go down the list and ask how to test each hypothesis.

10. Allow time for students to test each and draw some conclusions.

| Students write scientific explanations and arguments using the scientific explanation and argument base rubric (see Appendix 1) based on the modified CER Framework (McNeill et al., 2006). | Students write null and alternative hypotheses and use data collected in the activity to reject or fail to reject each hypothesis. |
# APPENDIX 14.
## GOLDFISH CELLULAR RESPIRATION EXPERIMENT

<table>
<thead>
<tr>
<th>Experimental Treatment</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives: Students should</td>
<td>Objectives: Students should</td>
</tr>
<tr>
<td>1. review the concepts of scientific explanation and argument and its components</td>
<td>1. review the scientific method and its components</td>
</tr>
<tr>
<td>2. understand the differences between gas exchange and cellular respiration, their relationship, and their importance.</td>
<td>2. understand the differences between gas exchange and cellular respiration, their relationship, and their importance.</td>
</tr>
<tr>
<td>3. write hypotheses, collect data, and a scientific explanation and argument discussing the effect of temperature on behavior of goldfish.</td>
<td>3. write hypotheses and collect data on the effect of temperature on behavior of goldfish.</td>
</tr>
<tr>
<td>Review scientific explanation and argument and its components (see Appendix 13)</td>
<td>Review the scientific method and its components (see Appendix 13)</td>
</tr>
<tr>
<td>What is Respiration?</td>
<td></td>
</tr>
<tr>
<td>Breathing and gas exchange: inhale oxygen and exhale carbon dioxide</td>
<td></td>
</tr>
<tr>
<td>Cellular respiration—aerobic respiration :Use food to create energy</td>
<td></td>
</tr>
<tr>
<td>Glucose (food) + O(_2) (inhaled) = Energy + CO(_2) (exhaled) + H(_2)O</td>
<td></td>
</tr>
<tr>
<td>THE MORE ENERGY YOU USE, THE MORE OXYGEN CONSUMED</td>
<td></td>
</tr>
<tr>
<td>Structures for Gas Exchange—membranes: thin, moist, highly vascularized (gills, lungs)</td>
<td></td>
</tr>
<tr>
<td>Aquatic Ectotherms—body temperature based on surrounding water</td>
<td></td>
</tr>
<tr>
<td>Low temp, low metabolic rates: rxns slow down, less oxygen, less food, sluggish animal</td>
<td></td>
</tr>
<tr>
<td>Low temp, high metabolic rates: rxns speed up, more oxygen, more food, same behavior</td>
<td></td>
</tr>
<tr>
<td>Students conduct goldfish cellular respiration experiment described in laboratory manual (White &amp; Campo, 2013, pp. 11-16).</td>
<td></td>
</tr>
<tr>
<td>Students write scientific explanations and arguments using the scientific explanation and argument base rubric (see Appendix 1) based on the modified CER Framework (McNeill et al., 2006).</td>
<td>Students write null and alternative hypotheses and use data collected in the experiment to reject or fail to reject each hypothesis.</td>
</tr>
</tbody>
</table>
APPENDIX 15.
DIFFUSION AND OSMOSIS EXPERIMENT

<table>
<thead>
<tr>
<th>Experimental Treatment</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives: Students should 1. be able to define diffusion and osmosis. 2. understand the effects of temperature on molecular movement. 3. understand the effects of surrounding environment on a cell. 4. write hypotheses, collect data, and a scientific explanation and argument discussing the effect of concentration gradient on osmosis.</td>
<td>Objectives: Students should 1. be able to define diffusion and osmosis. 2. understand the effects of temperature on molecular movement. 3. understand the effects of surrounding environment on a cell. 4. write hypotheses and collect data on the effect of concentration gradient on osmosis.</td>
</tr>
</tbody>
</table>

Review scientific explanation and argument and its components (see Appendix 13)

Diffusion: The movement of molecules from an area of high concentration to an area of low concentration, ie, perfume in a room, oxygen from lungs into blood stream

1. Brownian motion: the motion of molecules due to their energy, as energy increases movement of molecules increases, diffusion increases (add heat, add energy)

2. Concentration gradient: a difference in the concentration of a substance between areas.

Osmosis: the diffusion of water molecules across a selectively-permeable membrane

Selectively-permeable membrane: a barrier which lets some molecules across, but not all. Based on size of molecule: small can go across, gasses and H₂O; large cannot go across: sugars, proteins. E.g., cell membrane or dialysis tubing

Solutes (dissolved molecules; e.g., salt water: salt) vs. Solvent (substance that dissolves a solute; e.g., salt water: water)

The environment is: Hypertonic: higher concentration of solutes outside of the cell; Hypotonic: higher concentration of solutes inside the cell; Isotonic: equal amounts of solute inside and outside the cell

Students conduct diffusion and osmosis experiment described in laboratory manual (White and Campo, 2013, pp. 60-64).

Students write scientific explanations and arguments using the scientific explanation and argument base rubric (see Appendix 1) based on the modified CER Framework (McNeill et al., 2006). Students write null and alternative hypotheses and use data collected in the experiment to reject or fail to reject each hypothesis.
## APPENDIX 16.
### PHOTOSYNTHESIS EXPERIMENT

<table>
<thead>
<tr>
<th>Experimental Treatment</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objectives:</strong> Students should</td>
<td><strong>Objectives:</strong> Students should</td>
</tr>
<tr>
<td>1. understand the process of photosynthesis (PS).</td>
<td>1. understand the process of photosynthesis (PS).</td>
</tr>
<tr>
<td>2. understand the relationship between PS and cellular respiration in a plant.</td>
<td>2. understand the relationship between PS and cellular respiration in a plant.</td>
</tr>
<tr>
<td>3. measure net PS using a volumeter.</td>
<td>3. measure net PS using a volumeter.</td>
</tr>
<tr>
<td>4. write hypotheses, collect data, and a scientific explanation and argument discussing the effect of light energy on PS</td>
<td>4. write hypotheses using and collect data on the effect of light energy on PS.</td>
</tr>
</tbody>
</table>

Review scientific explanation and argument and its components (see Appendix 13)

Photosynthesis converts light energy into chemical energy that is stored in the bonds of carbohydrates such as glucose. Without light, no photosynthesis.

NET Reaction: \( 6 \text{CO}_2 + 6\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \)

(Opposite of cellular respiration NET reaction.)

Chlorophyll is the key light capturing pigment. It absorbs violet, blue, and red light, but reflects green light. This is why plants appear green.

**Light Reactions vs. Light Independent Reactions**

**Light Reactions:** Pigments absorb light E and make ATP, which is used for photolysis to break apart a water molecule into H and O. The oxygen is released from the plant. Hydrogen picked up and carried to the dark reaction by coenzyme NADP+ (NADPH)

**Light Independent Reactions:** ATP and NADPH convert CO2 into glucose. H atoms are combined with CO2, which is call carbon fixation \( \text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 \). Occur in light, because need products from light reaction

Students conduct photosynthesis experiment described in laboratory manual (White and Campo, 2013, pp. 77-82).

Students write null and alternative hypotheses and use data collected in the experiment to reject or fail to reject each hypothesis.
APPENDIX 17.
LOUISIANA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD EXEMPT FORM

Application for Exemption from Institutional Oversight

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/ Projects using living humans as subjects, or samples, or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This form helps the PI determine if a project may be exempted, and is used to request an exemption.

- Applicant, please fill out the application in its entirety and include the completed application as well as parts A-F, listed below, when submitting to the IRB. Once the application is completed, please the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://research.lsu.edu/CompliancePolicies/Procedures/InstitutionalReviewBoard#29B0%296exem24737.html

- A complete application includes all of the following:
  (A) A copy of this completed form and a copy of parts A thru F.
  (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 162)
  (C) Copies of all instruments to be used.
  (D) If this proposal is for a grant proposal, include a copy of the proposal and all recruitment material.
  (E) The consent form that you will use in the study (see part 3 for more information)
  (F) Certificate of Completion of Human Subjects Protection training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB (Training link: https://phrtraining.com/users/login.php)
  (G) IRB Security of Data Agreement (http://research.lsu.edu/files/exem26764.pdf)

1) Principal Investigator: Rosemary Becker
Dept: Education Ph: 815/861-2510
Rank: Doctoral Student
E-mail: rosemary.becker@lsu.edu

2) Co-Investigator(s): please include department, rank, phone and E-mail for each.
   If student, please identify and name supervising professor in this space.
   Pamela Blanchard, Education, 225/578-2297, pamb@lsu.edu

3) Project Title: Use of Explicit Instruction on Scientific Explanation and Argument in an Undergraduate Introductory Biology Laboratory Course

4) Proposal? (yes or no) NO If Yes, LSU Proposal Number
   Also, if YES, either: □ This application completely matches the scope of work in the grant
   □ More IRB Applications will be filed later

5) Subject pool (e.g., Psychology students) Undergraduate Biology Students
   *Circle any "vulnerable populations to be used: (children < 18; the mentally impaired; pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature: Rosemary Becker
   Date: 14 May 2005
   [signature]
   [initials]
   [number of signatures]
   ** I certify that my responses are accurate and complete. If the project scope or design is later changed, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted □ Not Exempted Category/Paragraph
Signed Consent Waived: Yes [O] □
Reviewer: Mathews [Signature]
Date: 24/12
APPENDIX 18.
SOUTHEASTERN LOUISIANA UNIVERSITY INSTITUTIONAL REVIEW BOARD FULL COMMITTEE REVIEW FORM

Institutional Review Board
Box 11851
Phone: 549-2077

DATE: May 22, 2013

TO: Rosemary Becker
Biology

FROM: Dr. Michelle Hall, Chair

RE: IRB Action on Proposed Project

This memo is to inform you of the IRB action with regard to your proposal:

Title: Use of Explicit Instruction on Scientific Explanation and Argument in an Undergraduate Introductory Biology Laboratory Course

This proposal was given:

- Expedited Review: 
- Full Committee Review: X
- Exempt: 

The result was:

- Full Approval: X
- Denied Approval: 

If anything other than Full Approval is recommended, it is your responsibility, as investigator, to submit changes/corrections or plans to accommodate conditions listed below to the Institutional Review Board prior to initiating the project. This approval is valid for one year from the date above, if data is to be collected after that time frame, the PI must submit a Continuation of Research Form.

Failure to acquire full approval by IRB before implementation for any project which involves humans means that the PI is not acting in "good faith" with university policy and is not, therefore, guaranteed the protection of the university.

Committee Comments:

IRB Number: 2013-204
APPENDIX 19.
INSTITUTIONAL REVIEW BOARD INFORMED CONSENT FORM

D. Becker

IRB-101-H

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8092 | www.lsu.edu/irb

Exemption Expires: 5/23/2016

Consent Form for Study Involving Only Minimal Risk
Use of Explicit Instruction on Scientific Explanation and Argument in an Undergraduate Introductory Biology Laboratory Course

Introduction: I, ___________________________, have been asked to participate in this study. Rosemary E Becker, who is conducting this research to fulfill the requirements for a doctoral dissertation in the Department of Education at Louisiana State University, has explained the study to me.

Purpose of the Study: The purpose of this research project is to understand how different instructional methods can influence student construction of scientific explanation and argument, student learning, and student understandings of science.

Description of Procedures: This study will be performed at Southeastern Louisiana University. I will be asked to complete a set of surveys and tests which take 10-30 minutes each (40-60 minutes total), participate in laboratory activities during my regular lab time, and complete assignments and exams already required of me to complete this course. The total amount of time for this study will be approximately ten hours which will take place during my regular class time. Approximately 96 participants will be in this study.

Risks and Discomforts: There are no known or expected risks from participating in this study.

Benefits: Increase in knowledge of scientific explanation and argument and potential for increased biological content knowledge, more expert-aligned views on the nature of science, and improved science literacy. I understand that this study may not benefit me but the knowledge gained may be of benefit to others.

Contact Persons: For more information about this research, I can contact Rosemary E Becker at 985/549-5296 or her supervisor, Dr. Pamela Blanchard, LSU School of Education, 225/578-2297. For information regarding my rights as a research participant, I may contact the Chair of the Institutional Review Board at 985/549-2077.

Confidentiality: I understand that any information obtained as a result of my participation in this research will be kept as confidential as legally possible. Neither my name nor any information from which I might be identified will be published without my consent. I understand that these research records, just like hospital records, may be subpoenaed by court order or may be inspected by federal authorities.

Voluntary Participation: Participation in this study is voluntary. I understand that I may withdraw from this study at any time. Refusal to participate or withdrawal will involve no penalty or loss of benefits for me. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand. Upon signing this form, I will receive a copy.

I willingly consent to my participation in this study. By signing below I verify I am 18 years of age or older.

Signature of Participant ___________________________ Date __________
Signature of Investigator ___________________________ Date __________

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APPENDIX 20.
INSTITUTIONAL REVIEW BOARD SURVEY COVER LETTER

Survey Cover Letter

A study is being conducted to understand how different instructional methods can influence student construction of scientific explanation and argument, student learning, and student views of the nature of science. Hence, we are conducting a survey to determine the views students currently hold on the nature of science within introductory biology laboratory courses. The second portion of the survey is to collect demographic data on participants.

The survey should take about 15-20 minutes to complete.

Thank you for participating in this survey. Your participation is voluntary. Completion of this survey will serve as voluntary consent to participate in this study. Participants’ identities will remain confidential and you may opt out of completing the survey at any time. You are not required to answer any questions you do not feel comfortable answering. This study is approved by Louisiana State University Institutional Review Board #E8104 as well as Southeastern Louisiana University Institutional Review Board #2013-204. If you have questions regarding subjects’ rights or other concerns, you may contact either Dr. Mathews at irb@lsu.edu or Dr. Michelle Hall at mhall@selu.edu.

Thank you again for your participation.

Rosemary E. Becker, M.S.
Instructor of Biological Sciences Southeastern Louisiana University
Louisiana State University Doctoral Candidate
rosemary.becker@selu.edu
rbecke3@lsu.edu
VITA

Rosemary Becker, the researcher and instructor for this study, grew up in the Chicago suburbs where she attended a small liberal arts college, North Central College, in Naperville, Illinois. She earned a Bachelor of Science in biology in 2005. From 2005 to 2008, the researcher attended Southeastern Louisiana University (SLU) in Hammond, Louisiana, where she earned a Master of Science in biology. After completion of her Master’s degree, Becker became an instructor at SLU teaching introductory biology and anatomy and physiology laboratory and lecture courses. After a year of teaching, she pursued a Doctor of Philosophy in Curriculum and Instruction with a focus in science education at Louisiana State University, in Baton Rouge, Louisiana, while continuing to teach classes at SLU.