2015

Inquiry-Based Teaching in the College Classroom: The Nontraditional Student

Daniel A. Kiernan
University of South Carolina - Columbia

INQUIRY-BASED TEACHING IN THE COLLEGE CLASSROOM: THE NONTRADITIONAL STUDENT

by

Daniel A. Kiernan

Bachelor of Arts and Science
Massachusetts College of Liberal Arts, 1998

Master of Biology
Central Michigan University, 2003

Submitted in Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy in

Secondary Education

College of Education

University of South Carolina

2015

Accepted by:

Christine Lotter, Major Professor

Stephen Thompson, Committee Member

Xiaofeng Liu, Committee Member

Jim Privett, Committee Member

Lacy Ford, Vice Provost and Dean of Graduate Studies

DEDICATION

This dissertation is dedicated to Leah, Caleb, and Julia who so graciously welcomed me into their family while on this doctoral degree journey. It was their support and the strength provided by our loving God that has allowed me to get to this point. Thank you all!

ACKNOWLEDGEMENTS

- Christine Lotter
- Jim Privett
- Xiaofeng Liu
- Stephen Thompson
- Britney Garvin
- Chris Bogiages
- Cory Fuller
- Leah Kiernan
- All my Biology 110 Evening Students from 2012 – 2014
- USC Sumter Tuition Assistance Program
- USC Columbia Department of Instruction & Teacher Education

ABSTRACT

Decline in the economic realm often bolsters an increase of nontraditional student enrollments in colleges and universities (Windolf, 1992). Many of these students, who do not desire to major in some scientific area, find themselves struggling in required science courses. Over the last decade, science departments of higher education have been adjusting their curriculum to include inquiry in the college science classroom. Although inquiry-based teaching has been shown to be very academically positive in science classrooms from K-12, "at the college level the data are mixed as to whether increasing inquiry instruction can significantly change students' learning or attitudes toward science" (Brickman et al., 2009, p. 3). To help delineate this controversy, more data are needed regarding the effectiveness of inquiry on students' conceptual understanding and attitudes toward science. Further, little research has addressed student academic and attitude changes when entire college science courses are transformed from traditional approaches to more inquiry-based approaches. Finally, investigations on how to improve the learning of nontraditional, nonscience major students taking science courses is absent from the literature. This study has added insight in helping address these gaps in this area of research. Anticipated hypothesis that inquiry would significantly generate a more positive attitude toward science was supported. However, anticipated hypotheses that inquiry would significantly impact attitude toward inquiry teaching and overall content achievement was rejected. However, inquiry students showed significant content achievement on questions dealing with the process of science or scientific practices.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Research Statement

Problem/Phenomenon/Issue

I believe we who teach in the field of higher education science need to focus more on developing critical thinking skills in our students. Critical thinking requires making connections with new information and that which is presently known and understood from past experiences. Further, I believe in active, in-depth learning in the science classroom. "I hear and I forget; I see and I remember; I do and I understand" (Darling-Hammond, 1997, p.55). Whether teaching lecture or lab, my goal is to facilitate active student involvement as well as I can and as often as I can. In teaching for understanding, I try to bring real life situations into my curriculum so that students don't just learn about science but *do* the science.

In considering these convictions, the goals of the following study were to investigate academic achievement and attitudes after a course structured around guided, inquiry-based labs followed by student and teacher discussion. This method of teaching was contrasted with a more typical way of teaching science courses in college, whereby cookbook-style labs follow lecture classes. This particular research project targeted only nontraditional students.

Nontraditional Students (Brief Overview)

Decline in the economic realm often bolsters an increase of nontraditional student enrollments in colleges and universities (Windolf, 1992; Sian Davies-Vollum & Greengrove, 2010). In an effort to make themselves more competitive as jobs decrease, students often return to higher education to obtain degrees of various sorts. Many of these students, who do not desire to major in some scientific area, find themselves struggling in required science courses. The Liberal Education and America's Promise (LEAP) initiative stresses the importance of a wide range of skills to adapt to changes in the twenty-first century (LEAP, 2011). Some have conducted research to focus on the academic needs of transfer students (Hoyt, 1999); while others have emphasized tutorials as a determining factor in helping nontraditional science students succeed in science courses (Eves, Davis, & Seward, 1990). Further, different teaching strategies have been offered with the goal of helping nontraditional students majoring in an area of life science (Deutch, Jurutka, & Marshall, 2008). Sian Davies-Vollum and Greengrove (2010) described the development of a course designed to help nontraditional student science majors prepare for upper-division science classes. A search of the literature, however, reveals a gap in addressing nontraditional nonscience majors taking science courses.

Generally viewed as a group that balances multiple responsibilities at school, work, and home, the nontraditional student has often been defined on an age-based criterion (Kim, Sax, Lee, & Hagedorn, 2010). For many years the age cutoff to be considered a nontraditional student has been 25 years of age or older (Metzner & Bean, 1987). Age alone has been shown to be a practical way to study nontraditional students within community colleges (Sundberg, 1997). Differences between traditional and

nontraditional students can sometimes be attributed to other factors besides age (Hughes, 1983). More current research emphasizes consideration of background characteristics (income / generational and employment status) and risk factors that affect attrition, such as enrollment and parental status as a way to further clarify the definition of a nontraditional student (Kim et al., 2010). The National Center for Education Statistics (NCES) defines the traditional student as one who enrolls in college full-time immediately after obtaining a high school diploma and works only part-time or does not work at all, relying on parents for financial support (U.S. Department of Education, 2003).

Inquiry (Brief Overview)

For over fifty years, the overall goal of many science educators has been to include more inquiry-based teaching in their instruction (DeBoer, 1991). Over the last decade, science departments of higher education have been adjusting their curriculum to include inquiry in the college science classroom. Whether the shift has occurred in the lecture part of the course or in the laboratory part of the course, a clear trend has been apparent (Brickman, Gormally, Armstrong, & Hallar, 2009; Knight & Wood 2005; Sundberg, Armstrong, & Wischusen, 2005; Wallace, Tsoi, Calkin, & Darley, 2003). Some studies at the collegiate level have described the use of inquiry-based instruction for teaching certain topics or laboratory exercises (Rissing & Cogan, 2009). However, few studies have addressed changes in science achievement and attitudes toward science classes when entire courses are converted from traditional approaches to inquiry-based approaches (Brickmen et al., 2009).

Using inquiry to organize a curriculum depends on a thorough understanding of inquiry. Inquiry has different meanings to different people. According to the *National Science Education Standards* (NSES) set by the National Research Council (1996), inquiry is referred to as scientific inquiry, which points to an expression of the nature of science or doing the work of scientists. Secondly, inquiry is often seen as inquiry learning. This view is referred to as something students do and is not done for them and is dependent on prior knowledge. Further, the understanding is context dependent and is socially constructed. Finally, inquiry can be referred to as inquiry teaching. Although varied and not well understood, it has multiple manifestations. The only way to test if inquiry teaching is going on is to determine whether students are engaged in inquiry learning (Anderson, 2007). To bring further clarification to the understanding of inquiry, the *National Science Education Standards* (NSES) describes five essential features of inquiry in understanding the natural world. These five characteristics that can be used to describe the process by which scientific inquiry manifests in the classroom are: learners must be involved in scientifically oriented questions, a focus on the evidence is given priority when learners respond to questions, learners are to give explanations from the evidence provided, learners explanations are to be connected to scientific knowledge, and lastly, students are to communicate and justify their proposed explanations (National Research Council, 2000). A variety of models of inquiry-based teaching can be used depending on each unique teaching situation (Keys & Bryan, 2000). In this project, I focused on the following activities described by *NSES* over the years: observing, asking questions, submitting hypotheses, designing experiments, collecting and analyzing data, and comparing previous hypothesis with new experimental data. However, a "guided

inquiry” approach according to Brickmen et al. (2009) was used to reduce student frustration levels, especially involving those who have never learned under inquiry before. In this approach, the problem is presented by the instructor who then guides the students in: “selecting variables, planning procedures, controlling variables, planning measures, and finding flaws through questioning that will help students arrive at a solution” (Brickmen et al., 2009, p. 2).

The main goal for this shift to an inquiry pedagogical approach in higher education science courses has been to better prepare scientifically literate citizens. However, the collegiate literature is mixed as to whether inquiry instruction really increases scientific knowledge or engenders more positive attitudes toward science (Berg, Bergendahl, Lundberg, & Tibell, 2003; Hake, 1998; Luckie, Maleszewski, Loznak, & Krha, 2004; Nueby, 2010; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). In addition, little research has been done to compare higher education inquiry-based curricula with more traditional curricula (Brickman et al., 2009). Further, a handful of inquiry studies have been conducted looking at college student “fundamental” knowledge and fewer have focused on looking at college student “derived” knowledge. “Derived” knowledge includes the ability to use what one understands to accurately interpret and evaluate scientific material, as opposed to “fundamental” knowledge which involves simple recall (Norris, Phillips, & Korpan, 2003). Other inquiry-based studies at various campuses have focused more on student attitudes toward science (Berg et al., 2003). The research is very sparse, however, in comparing these variables with nontraditional college students.

Conceptual Change - Major Theoretical Foundation (Brief Overview)

Students have many different ideas about the natural world. These ideas can be as diverse as the backgrounds of the students themselves. Unfortunately, some of these ideas are different from those generally accepted by scientists. These ideas or misconceptions can persist throughout a student's academic career, making scientific understanding confusing (Tekkaya, 2002). Informing students of scientific questions is not enough to change alternative conceptual understandings (Hakkarainen & Ahtee, 2006). The theoretical framework upon which I built my research was conceptual change. Alkhawaldeh (2007) states: "Conceptual change implies that a learner actively and rationally replaces existing prescientific conceptions with scientific, acceptable explanations as new propositional linkages are formed in his conceptual framework" (p. 372). In their seminal paper on conceptual change in science learning, Posner, Strike, Hewson, and Gertzog (1982) give no formal definition of conceptual change; however they do state that accommodation requires certain conditions. Scott, Asoko, and Leach (2007) described these four conditions well: "These conditions are that a learner must first be dissatisfied with existing ideas and that the new ideas must be seen as intelligible, plausible, and fruitful" (p. 36). Since the time of Posner et al.'s work, much has been done regarding conceptual change in science learning. Scott et al. (2007) in talking about Hewson's 1981 work stated that: "during conceptual change the status of different ideas within a person's conceptual ecology changes" (p. 36). Although different views of conceptual change exist (Chi & Roscoe, 2002; DiSessa, 2002; Ivarsson, Schoultz, & Saljo, 2002; Vosniadou, 2002), most science educators embrace the conceptual change model (CCM) as an effective way to approach science teaching.

Social Constructivism & Situated Cognition - Other Theoretical Foundations

Two other theories clearly emerged by the end of this study. I find it advantageous to include a brief description of these theories here and explain how they are related to each other and to the theory of conceptual change. This background will provide a foundation for eventually describing the presence of these theories within the qualitative data under objective four. These two theories are social constructivism and situated cognition. Social constructivism is a theory of constructivism that includes the role of society and culture in cognitive construction (Peters & Stout, 2011). Brown, Collins, and Duguid (1989) described situated cognition theory as learning within practical activity and within the environment of real life context and culture.

The philosophy of cognitivism is based on the belief that it is through experience that people actively construct their knowledge of the world (R. McNergney & J. McNergney, 2009). Cognitivists believe in student-centered active learning through one's own direct experiences and interactions. Constructivism theory was actually adopted because of certain educators who wanted to modify curriculum and instruction to reflect cognitivists views (R. McNergney & J. McNergney, 2009). Within the theory of constructivism, knowledge is not passed from teacher to student but teachers function as facilitators, creating learning situations by which students can construct new knowledge (R. McNergney & J. McNergney, 2009). Corbern (1993) uses an analogy of a construction site to describe the constructivist approach to teaching. Existing structures are considered to be the foundation upon which to build new knowledge. Social or Vygotskian constructivism includes the impact of culture and society on mental development. This is different from personal constructivism: "because scientific

knowledge is the product of the scientific community, it cannot be learned through interactions with the material world alone" (Scott et al., 2007, p. 41). But how is knowledge really constructed? Some kind of change is going on in the cognitive realm of the learner. To try to explain how knowledge is constructed, the conceptual change learning model was formulated (Posner et al. 1982). Social constructivism is differentiated from conceptual change in that conceptual change is a theory of how cognitive construction of knowledge might be occurring or how knowledge is acquired. As social exchanges occur (social constructivism) rather than just experiencing learning by oneself, the chances of experiencing intelligible and rational conceptual insights is increased. Now, where does situated cognition fit into all this? Social constructivism and conceptual change focus more on knowledge as acquisition, whereas situated cognition focuses on knowledge as participation (Anderson, 2007). If knowledge attainment is enhanced by social construction and undergoes conceptual change, then it would make sense to situate learning in an environment and culture that would further maximize this process. Posner et al.'s (1982) four requirements are not enough to bring about conceptual change. Other things such as contextual factors need to be considered (Anderson, 2007). Brown et al. (1989) states that teaching abstract concepts independently of authentic situations is like acquiring a tool without being able to use it, and thus is not productive in producing understanding. In the scientific world, concepts are continually evolving as they are applied in different contextual situations (Brown et al. 1989). Efforts must be made to bridge the gap between the science classroom and the real life scientific context and culture. Brown et al. (1989) suggests a shift in the way we teach through the concept of apprenticeship thinking. We as science teachers must bring

the scientific context and culture into our classrooms with activities that mimic what goes on in the scientific research world. Activities should include real life problems that require self-generated questions, the use of knowledge from multiple disciplines, coaching and modeling, and collaborative work with discussion and reflection. The ultimate goal should be to empower students to become independent thinkers (Brown et al. 1989).

Research Purpose

The purpose of this study was to address the following overarching question: Does a science curriculum that is inquiry-based versus a science curriculum that is more traditionally-based, produce more positive academic results in nontraditional, nonscience major, college students? Data gleaned from both quantitative and qualitative methods helped answer this question. This study is significant in that it was one of the first to explore the differences between traditional methods of teaching at the college level versus inquiry-based methods in nontraditional students. Traditional methods of teaching at the college level have, for the most part, been in a lecture format as the teacher dispenses knowledge to the students and in a cookbook lab pattern whereby students follow step-by-step instructions. This may work well in dispensing factual information, but this type of teaching has not been shown to effectively bring about conceptual understanding (National Research Council, 1999). Intellectually, I have taken steps in understanding how inquiry-based teaching as opposed to more traditional forms of teaching impacts students in the college science classroom. Further, I have contributed to the understanding of the literature regarding the science learning of nontraditional students who are not majoring in a scientific field.

Major Research Questions

My objective in this study was to address the following research questions involving nontraditional college students who were not majoring in a scientific area: (a) Does guided inquiry-based teaching followed by student and teacher discussion ("explore before explain") bring about higher science achievement compared to lecture teaching followed by cookbook lab confirmation ("explain before explore")? (b) Does guided inquiry-based teaching followed by student and teacher discussion (explore before explain) versus lecture teaching followed by cookbook lab confirmation (explain before explore) result in students with more positive attitudes toward science in school? (c) Are nontraditional students' attitudes more positive toward learning through guided inquiry-based teaching followed by student and teacher discussion (explore before explain) as opposed to lecture teaching followed by cookbook lab confirmation (explain before explore)? (d) How do nontraditional students perceive an inquiry-based curriculum differently than a traditionally-based curriculum?

I anticipated that positive academic results after an inquiry-based course would significantly exceed those found after a traditionally-based course. My three hypotheses at the beginning of this study were as follows: If inquiry-based labs followed by discussion bring about higher science achievement as compared to lecture followed by cookbook labs, then students who learned under the inquiry-based format will experience higher science achievement as shown on a content related diagnostic test when compared to their counterparts who learned under the lecture/cookbook format. Further, if student attitudes are more positive toward science as a subject in school after being exposed to the inquiry-based course in comparison to the traditionally-based course, then students

who learned under the inquiry-based course will experience a more positive attitude toward science classes as assessed by an attitude survey when compared to their counterparts who learned under the traditionally-based course. Lastly, if students enjoy the inquiry-based style class more than the traditionally-based style class, then students who learned under the inquiry-based class will experience a more positive attitude toward inquiry-based teaching as assessed by an attitude survey when compared to their counterparts who learned under the traditionally-based class.

Type of Study (Methodology)

Action research, which was originally grounded in the positivist paradigm and is now based in interpretivism (observing, reflecting, & acting) has been a popular methodology used in many different settings (Glesne, 2011). Teacher (Action) oriented research, which is a form of "backyard" research where one "inquires into one's own institution, agency, or community" (Glesne, 2011, p. 279) or in this case, one's own classes, was chosen as the methodological lens through which to conduct this inquiry. Approaching this investigation through this methodology allowed me to improve my own educational practice through using surveys, quantifiable data and qualitative interviews with my own students. Through using a convergent parallel mixed methods design, I was able to ascertain insight into the positive and negative academic results in nontraditional, nonscience major, college students learning under different teaching styles. Functioning as a practitioner and a researcher, I served as an agent of change in my own "backyard" or own classroom.

CHAPTER 2

LITERATURE REVIEW

This chapter will provide a discussion of the literature regarding inquiry-based teaching and curriculum. The relevant literature on this topic is then explored at the collegiate level and from a college biology perspective. A review of the literature on nontraditional students is presented prior to a discussion of the theoretical perspective conceptual change. Conceptual change strategies and instructional methods are separated by a discussion of the studies on conceptual change in biology. The chapter ends with a concluding subjectivity statement.

Conceptual Framework

Inquiry-based Instruction

The push toward inquiry teaching and learning in science goes all the way back to the early nineteen hundreds. John Dewey stated:

> As Mrs. Young has recently said, the prevailing ideal is a perfect recitation, an exhibition without mistake, of a lesson learned. Until the emphasis changes to the conditions which make it necessary for a child to take an active share in the personal building up of his own problems and to participate in methods of solving them (even at the expense of experimentation and error), mind is not really freed. (1903, p. 201)

John Dewey, a former science teacher clearly felt that too much emphasis was being put on facts without enough focus on thinking like scientists. He encouraged teachers to be

facilitators and guides instead of dispensers of information. Dewey stressed that students should be active learners in trying to find relevant answers that were within student's experiences and capabilities (Dewey, 1903). German physicist and teacher, Martin Wagenschein was also a pioneer in exploring the value of inquiry-based instruction. He emphasized that students should not be taught straight facts, but should be directed toward conceptual understanding. A popular example of this was when he asked physics students to tell him what the speed of a falling object was. Nearly all students produced equations. But no student could explain what their equations meant. Wagenschein demonstrated the fruitlessness of recitation over conceptual understanding (Wagenschein, 1999; 1957).

After the launching of Sputnik in the 1950's many Americans began to seriously question the science curriculum used in schools. Around this time the National Science Foundation began to fund research in physics and other science related fields that emphasized "thinking like a scientist" (Deboer, 1991). Inquiry related research began to grow heavily during what many would eventually call the discovery learning movement of the 1960's. This movement was partially sparked by a paper written by Bruner (1961). In his work Bruner emphasized the failure of more traditional forms of instruction, where students were required to simply memorize factual information. Novak (1964), in emphasizing that inquiry-oriented instruction engages learners in the investigative nature of science, stated that inquiry-based curriculum should involve activities and skills that build knowledge and understanding based on curiosity. Recommending that teachers have a background in the history and philosophy of science, Rutherford (1964) believed that inquiry learning should be context based. He believed that context was a major key

toward sparking future inquiry. With the goal of emphasizing that not all inquiry-based activities are equal, Schwab (1962) described different levels of inquiry. In the 1970's Herron (1971) formalized Schwab's work into three distinct levels of openness for inquiry in science activities. This work was eventually built upon by Rezba et al. (1999) who developed a four-level model of inquiry instruction. Bell, Smetana, and Binns (2005) describe these four levels well:

> (a) Confirmation (Students confirm a principle through an activity in which the results are known in advance) (b) Structured Inquiry (Students investigate a teacher-presented question through a prescribed procedure) (c) Guided Inquiry (Students investigate a teacher-presented question using student designed/selected procedures) (d) Open Inquiry (Students investigate topic-related questions that are student formulated through student designed/selected procedures). (p. 4)

As described earlier in this paper, an even more detailed outline can be found in *Inquiry and the National Science Education Standards* (NRC, 2000, p. 2).

The impact of inquiry-based research on students' overall academic success and experiences in the science classroom has grown steadily and has been reported consistently in the educational literature. In the 1960s and 1970s, new inquiry curriculum projects were abundant. Examples included the Biological Sciences Curriculum Study (BSCS) in biology, the Physical Sciences Study Committee (PSSC) materials in physics, Science Curriculum Improvement Study (SCIS) and the Elementary Science Study (ESS) units for elementary school science. Shymansky, Hedges, and Woodworth (1990) reassessment of their earlier 1983 investigation using refined statistical procedures with greater precision, found that "the new science curricula of the 60's and 70's were more

effective in enhancing student performance than traditional textbook-based programs of the time" (p. 1). Curriculum that is based on inquiry-based teaching has been shown to develop students' curiosity and positive attitudes toward science, independent and critical thinking skills and ultimately increased conceptual understanding of biological content (Hall and McCudy, 1990; Kyle, Bonnstetter, & Gadsden, 1988; Shymansky, 1984). Further, Haury (1993) reported on how inquiry-related teaching is effective in fostering scientific literacy and understanding of science processes (Lindberg, 1990), vocabulary knowledge (Lloyd & Contreras, 1985), higher achievement on tests of procedural knowledge (Glasson, 1989), and construction of logico-mathematical knowledge (Staver, 1986). Positive inquiry-based research such as these just described helped inquiry-based instruction catch national focus in the 1990's. In 1996, the National Research Council (NRC) released the *National Science Education Standards* (*NSES*). The authors stated the following about inquiry: "a new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (p. ix). The goal of thousands who played a role in bringing about the *NSES* was to have science classrooms of all ages match the diverse process of discovery used by real scientists. The vision was to have learners "observing phenomena; developing personal questions, predictions, or hypotheses to explore; gather information to see what has already been discovered; using various tools to collect, organize, analyze, and interpret data; proposing answers to the initial hypothesis; and finally, communicate results" (Peters & Stout, 2011, p. 3). Although Kirschner, Sweller, and Clark, (2006) argue that NSES's portrayal of inquiry ideals are in conflict with the realities of the classroom, inquiry-based teaching and research continues to grow in

popularity. Recently the National Research Council of the National Academy of Sciences released a new science education framework called “A Framework for K-12 Science Education Practices, Crosscutting Concepts and Core Ideas” (NRC, 2012). Instead of focusing on inquiry, they discuss science practices and ideas. Elements are organized into three dimensions as the title indicates. NRC’s 2012 report highlights each dimension with dimension one directing attention to scientist and engineering practices such as modeling, developing explanations or solutions, and engaging in argumentation. Dimension two notes concepts that have common application across fields connecting knowledge into coherent and scientific views of the world. Dimension three emphasizes the “less is more” analogy in preaching a limited number of core ideas in science and engineering and stresses depth and understanding (NRC, 2012).

Inquiry-based Curriculum Changes

Changing from a curriculum that is traditionally-based to a curriculum that is inquiry-based requires much work. Anderson (2007) sees inquiry-based curriculum changes that involve the external and internal. He sees external curriculum changes as content, program of planned activities, intended learning outcomes, discrete tasks and concepts. These characterizations are considered external because “the goals and choice of student experiences have origins largely external to the students” (Anderson, 2007, p. 819). Internally, he views curriculum changes as experience and “currere” (self-understanding). These images of curriculum changes “are more personal and have origins more internal to the students” (Anderson, 2007, p. 819). For example, in changing a college biology curriculum from a traditional curriculum to an inquiry-based curriculum it is important to decide on one’s goals. If an understanding of the nature of science and

exemplary inquiry is the goal, then one needs to consider giving attention to the emotional aspects of the experience of being engaged in science inquiry. Anderson (2007) states: "Rather than having these experiences predetermined, there is value in having student choice of hypotheses tested, means of doing such testing, and interpretations to be placed on the results" (Anderson, 2007, p. 819). Real scientific work involves internal turmoil at certain times and great internal triumph at other times. These experiences can be invaluable (Anderson, 2007). The exemplary level of inquiry (Level 4) depends on giving the students power and responsibility for their own learning and often stimulates self-understanding (Marshall, Horton, & White, 2009).

Further, Anderson (2007) emphasizes that change efforts toward inquiry must be systemic in nature. Newmann et al. (2004) and Anderson (2007) both describe how teachers face many dilemmas such as inquiry taking more time, changing roles and an increase in work load, a feeling that preparation will suffer, and fear of how problematic students will react in an atmosphere with less learning constraints. According to Roehrig and Luft (2004), in light of these significant changes educational practice requires changes in teacher's beliefs and values, changes in school departments, changes in teacher collaboration, and changes in parental support. To see inquiry-based instructional change, Anderson (2007) stresses the need for good curriculum materials and a strong support system that is systemic. He states that the systemic aspects of change are diverse. They include teachers' professional growth and vision of education, a teacher's materials and work environment and much teacher collaboration. Further, change is also dependent on teacher empowerment, policy makers, and administration.

Inquiry at the Collegiate Level

Most of the research on science classroom inquiry has been associated with precollege classrooms (Brown, Abell, Demir, & Schmidt, 2006). Much of it has focused on inquiry as a teaching approach and has been shown to be very positive (Anderson, 2007). For example, Blanchard et al. (2010) compared guided inquiry-based instruction to verification laboratory instruction in middle school and high school students. It was found that: "students receiving guided inquiry-based laboratory instruction on concepts related to forensics tended to have stronger gains in various types of knowledge and generally better long-term retention over time than students that received traditional, verification laboratory instruction" (Blanchard et al., 2010, p. 609). In 1983 William Leonard showed that college students who completed a semester long basic biology laboratory designed on inquiry-based approaches achieved 6% higher grades on biology content tests as opposed to the control group which completed a more traditional factual-transmission modeled laboratory. Signs of early success of inquiry-based instruction at the college level sparked a steady change in the way college science courses began to be taught, especially in the laboratory.

Inquiry-based curriculum transformation at colleges and universities however has not been without its resistance. In 1999 Longbottom and Butler still found that most higher education science lectures were being taught by dispensing a myriad of facts leading to student ignorance of the role of how scientists actually practice science. Seymour and Hewitt (1994) found out that a major complaint from students taking science classes on different campuses was poor teaching. Among reasons of why students were displeased with their professors included an overemphasis on factual information

that did not seem relevant. Further, the *National Science Board* (NSB, 1996) found most laboratories being used catered toward verifying lecture material by asking students to follow a recipe, instead of engaging students in inquiry activities. This problem was recognized and recommendations were made on how to improve undergraduate science education. They stated:

> Covering the history of the field, demonstrating the process of discovery, or presenting other stories as examples of how scientists work—while clearly illustrating why the knowledge that has been gained is relevant to the lives and surroundings of the students—is an excellent way to engage undergraduates. (Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, 2003, p. 3)

For many higher education facilities, instructors find that the challenge of appropriating inquiry-based teaching outweighs the benefits of implementing it. Common justifications for not exploring inquiry in their classrooms include: the constraints of multicourse teaching loads, large lecture courses, and competing faculty responsibilities such as research and outreach (Brown et al., 2006). Although challenges exist, inquiry research at the collegiate level has been building over the years. Much of this research has come in physics courses. Price, Vigeant, and Nottis (2009) gave a nice background of this work, which helped inform this section. Hake's (1998) investigation on introductory physics courses found that inquiry-based methods significantly improved student's conceptual understanding of physics compared to teaching that was more traditional. Classes promoting active learning resulted in test scores nearly twice as high as classes applying traditional methods. Laws, Sokoloff, and Thornton (1999) demonstrated

positive active learning results using data of physics education research. They demonstrated that the percent of students who understood the concepts of force, acceleration and velocity went up significantly after learning under an active-engagement teaching style. In fact, active-engagement student learning gains were over double for all three topics compared to that of the traditional instruction student learning gains. Redish, Saul, and Steinberg (1997) demonstrated that conceptual understanding improvements with the use of inquiry-based instruction versus traditional-based instruction were due to the type of teaching rather than time on task or the quality of the instructor. In addition, Beichner and Saul (2003) further strengthened the support for inquiry-based teaching as they showed that students in large lecture university physics courses learn substantially more from active inquiry-based activities and problem solving than from listening to lectures on physics. Results from this study showed that conceptual understanding and the ability to solve problems got better, attitudes improved, failure rates decreased significantly (especially for women and minorities), and performance was enhanced in follow up science classes.

Inquiry & College Biology

In the life sciences, inquiry-based teaching is growing among introductory biology courses and has shown positive academic results. Most of this inquiry focused growth has occurred in the laboratory portion of courses. Sundberg et al. (2005) describes a strong trend in the laboratory toward student-active inquiry and process-based science instruction. The change is clearly apparent:

> Today most schools report using inquiry in the laboratory: 79% of research universities, 88% of comprehensive universities, and 71% of liberal arts colleges.

> Particularly noteworthy is that half of the liberal arts colleges (50%) report using open investigations in their introductory courses. (Sundberg et al., 2005, p. 527)

Although a host of publications describe ongoing efforts to implement inquiry in the college science classroom (Crandall, 1997; Glasson & McKenzie, 1998; Harker, 1999; Stukus & Lennox, 1995; Sunal, Wright, & Day, 2004; Tichenor, 1997; Tolman, 1999; Weld, Rogers, & Heard, 1999), including how to use inquiry-based instruction in non-laboratory settings (Ingram, Lehman, Love, & Polacek, 2004; Reeve, Hammond, & Bradshaw, 2004), most work is descriptive and more empirical work needs to be done.

Experimental research on inquiry-based instruction in the laboratory setting has been reported on in the literature. Brickman et al. (2009) undertook a huge project of implementing an inquiry based curriculum in college nonmajor's biology laboratory classrooms. The large goal of their work was to compare changes in the variables of science literacy, science process skills and self-confidence of students taught using a "guided inquiry" lab teaching approach as opposed to a more traditional "cookbook" lab teaching approach. Significant gains in science literacy and skills were found to be greater in students who enrolled in the inquiry-based labs verse those enrolled in the more traditional labs. Significant improvements in inquiry-based lab students' confidence to use science literacy skills were clearly evident. Gormally, Brickman, Hallar, and Armstrong (2011) reported on the lessons learned and some details from the Brickman et al. (2009) research project. It was clearly noted that implementing an inquiry-based curriculum was not only difficult for instructors to put together but also to teach depending on their prior experience with this style of teaching. Further, Gormally et al. (2011) talked about how the inquiry-based labs engendered frustration from many

students because they were not used to the mental effort required of them. This mental exertion ended up being one of the reasons the study reported resistance among students when explaining their inquiry-based experience. However, it was apparent through student interviews that although inquiry students portrayed resistance to inquiry-based labs, most did admit a sense of satisfaction in working hard and learning. Brickman et al.'s (2009) work further supports the goal of many college and universities to incorporate more inquiry-based instruction into the science curriculum. Further, Wallace et al. (2003) conducted a smaller study that focused on five nonscience major students' experiences with an inquiry-based biology laboratory course. A heavy focus on conceptual maps and student interviews revealed that all students improved their understanding of experimental biology and preferred the inquiry-based labs over the cookbook style labs. An interesting finding was that students with constructivist learning beliefs tended to add more meaningful conceptual understanding during inquiry labs than students with positivists or more traditional learning beliefs. Implications of this might mean that college professors need to teach constructivists learning strategies to those involved in inquiry. This might take the form of teaching the thinking strategies of scientists.

The impact of inquiry-based instruction on isolated biological concepts has been reported on in the literature. Rissing and Cogan (2009) focused on looking at inquiry-based teaching versus traditional based teaching of one biochemistry concept in a college biology lab course. Students who were taught the exercise via inquiry had significant increases on both objective and subjective questions as compared to those taught through more direct instruction. Furthermore, student self-evaluation of their conceptual

understanding of and confidence with the information and techniques presented in a typical enzyme lab increased after experiencing an inquiry-based approach to learning about enzymes as opposed to learning about enzymes in the more traditional way. Student centered inquiry-based approaches for teaching biology concepts were also successful in teaching cellular biology concepts and anatomy and physiology concepts (Christianson et al., 1999; Lunsford & Herzog, 1997).

Empirical research on inquiry-based instruction in a non-laboratory setting has also been researched. Knight and Wood (2005) produced an article called “Teaching More by Lecturing Less.” This journal article discussed an experiment comparing traditionally taught lectures which focused on dispensing factual knowledge with more interactive inquiry-based lectures that focused more on collaborative activities, problem solving, analytical skills, and critical thinking. They found that “even a partial shift toward a more interactive and collaborative course format can lead to significant increases in student learning gains” (p. 304). Further it was found that students who experienced the inquiry class developed better skills for solving conceptual problems than those who experienced the fact laden lecture format. Magnussen, Ishida, and Itano (2000) also showed how inquiry-based methods of teaching in a nonlaboratory setting can positively affect student performance. They concluded with the following statement: “In summary, the results suggest that this methodology appeared to be more effective in developing critical-thinking skills for students whose scores were initially low” (p. 364). Other studies investigating inquiry at the college level showed little or no benefit to academic achievement (Neuby, 2010). More research is needed in this area.

Inquiry & Attitudes Toward Science

Positive attitudes toward science can impact success in science courses. Further, positive attitudes about science after completing science courses are vital to generating lifelong learners of science, which engenders well informed scientifically literate citizens. Berg et al. (2003) used an inquiry-based biochemistry experiment to look at student personal attitudes toward science teaching, learning and experimental work. A positive association between inquiry-based learning and attitudes toward science was noted. House (1996) found positive connections between student attitude toward science and success in science classes. In this study, students showed greater self-efficacy after inquiry experiences. However, the relationship between inquiry-based teaching and student attitude toward science is indefinite. Alouf and Bentley (2003) showed a positive correlation, while others like Kirschner et al. (2006) argued for no connection at all. The jury is still out regarding the effectiveness of inquiry-based teaching to stimulate positive attitudes toward science.

Nontraditional Students

In 2004 Senator Clinton unveiled a plan to help nontraditional students. The Nontraditional Student Success Act (S. 301) is a bill that has been in congress for some time now and although it has not passed as of yet, the push to help nontraditional students has been growing (Lane, 2004). According to Windolf (1992) in times of economic pressure when people are out of work, attendance at colleges and universities often grows in enrollment. Research targeting the nontraditional student has been found in the literature for many years now. In 2001 Bowl published a paper describing the barriers nontraditional students face when entering higher education. He urged changes in

institutions of higher education to meet the diverse needs of nontraditional students. Turner (2006) wrote an article about her efforts to help nontraditional students succeed. As president of an urban college in Boston, she created a program to provide culturally competent mentoring to nontraditional students on her campus. Houser (2005) conducted a study on nontraditional student instructor communication expectations. It was revealed that nontraditional students have different expectations on how instructors should communicate. Strage (2008) investigated nontraditional college students' descriptions of what they thought was the "ideal" professor and college course. The learning environment that nontraditional students preferred the most was "by and large, more rigorous, more serious, and more readily applicable to the real world" (p. 225). Another study investigated the learning environment and learning style of nontraditional students (Buerck, Malmstrom, & Peppers, 2003). Nontraditional students were compared regarding those that preferred internet-based versus those that preferred lecture-based computer science courses. It was found that although differences in learning style existed, computer science students enrolled in the internet-based course performed as well as those enrolled in the face -to-face lecture-based course. Also in 2003 Jane Manner wrote an article talking about her experiences with nontraditional students taking her online classes. She writes "They are newcomers who arrive on campus hoping to forge new lives for themselves, but like e-immigrants, have never learned the language or customs of the receiving land" (p. 32). She describes different ways to enhance the curriculum, such as providing opportunities for nontraditional students to experience "discovery". She describes how the students discovery of new technological skills was more exciting for them than what they covered by completing the objectives in the course catalog.

Wyatt (2011) in a review article described the challenges in engaging nontraditional students. He found that student engagement increased with curriculum reform and faculty experience.

Research investigating nontraditional students' academic success and attitudes surrounding science coursework is absent from the literature. Most studies address the complex social and logistical issues that nontraditional students face. Those surrounding science investigations cater more toward support and remediation. Kimbrough and Weaver (1999) described an investigation to improve the math and science background of nontraditional students. The authors demonstrated the use of action research in developing an effective method of addressing nontraditional student background deficiencies. Research has even been conducted to investigate nontraditional student's anxiety involving statistics courses. It was found that nontraditional students suffered more from test and class anxiety as opposed to their younger counterparts (Bell, 1999). Bell (1999) suggests that the reason for this might be because nontraditional students take tests and class time more serious than the traditional student does. Deutch et al. (2008) discussed the pedagogical issues involved with teaching upper-level science courses at a community university that enrolls many nontraditional students. Due to students' work and family responsibilities, recommendations were offered on how to better cater to nontraditional and transfer students in difficult science classes. Accommodations discussed were sensitivity toward textbook and course content selection, PowerPoint supporting materials, supplementary handouts and activities, exam question variety to assess student success and project type inquiry-based labs. Finally, tutorials and a course to prepare students for upper-division science classes were created to help with

nontraditional student retention (Eves et al., 1990; Sian Davies-Vollum & Greengrove, 2010). Nontraditional student course weaknesses were found in the area of technology use, writing, presenting, career planning, and critical thinking.

Theoretical Perspective

Conceptual Change

Science teaching and learning has been heavily impacted for many decades now because of the twentieth century foundational work of Jean Piaget. “Piaget described an interactive learning process whereby an individual makes sense of the world through cognitive schemes, which are themselves modified as a result of the individual’s actions on objects of the world” (Scott et al., 2007, p. 32). Piaget used the terms *assimilation* and *accommodation* in describing how the mind adapts to organize information (Piaget, 1952). According to Scott et al. (2007) *assimilation* occurs when a person interprets new information and includes it in his or her existing cognitive schemes, while *accommodation* is when cognitive structures adapt to make sense out of information. Piaget’s work on assimilation has been identified with a philosophy of learning called *constructivism*. Although not always clearly defined in the literature, constructivism is a learning theory that has strongly influenced science educators. According to Colburn (2000), constructivism is the belief that knowledge is not passed on from the teacher to the student, but rather it is constructed by a person as he or she creates his or her own world view. Corbern (1993) uses an analogy of a construction site to describe the constructivists approach to teaching. Existing structures are considered to be the foundation upon which to build new knowledge.

As science epistemology continued to evolve from the groundwork of Piaget and others, Posner et al. (1982) constructed a representation to explain science learning called the “conceptual change” learning model. In this classic paper, Posner’s team discuss a model of conceptual change which articulates the process by which people's central, organizing concepts change from one set of concepts to another set that is incompatible with the first. Learning is a rational activity whereby ideas are accepted because they make sense and fit with available evidence (Suping, 2003). Shortly before this paper was published, Hewson (1981) began to talk about a person’s adjusting conceptual ecology and its role in changing an individual’s conceptions. Scott et al. (2007) defines a person’s conceptual ecology as “the range of ideas they hold” (p. 36). Making mental connections about the natural world over many years forms what Özdemir and Clark (2007) describe as a "web-based relationship between concepts” (p. 352). They state that because of this conceptual labyrinth, correcting misconceptions requires revisions to multiple concepts. According to Suping (2003) conceptual ecology is vital because “without such concepts it is impossible for the learner to ask a question about the phenomenon, to know what would count as an answer to the question, or to distinguish relevant from irrelevant features of the phenomenon” (Posner et al., 1982, p.212). Without forming a conventional definition, Posner et al. (1982) state clearly that accommodation to form an idea requires first that conceptions that are already present must be dissatisfying and that new conceptions must be intelligible (able to be related to some existing conceptual framework), appear initially plausible (having more explanatory power or providing solutions to problems) and have the prospect of being fruitful (providing the potential for new insights and discoveries).

Over the years others theorists have offered conceptual change models with the goal of bringing more clarity to how accurate scientific ideas can replace scientific misconceptions. Suping (2003) summarized these models nicely in her 2003 work, which helped inform this portion of this review. In acknowledging prior knowledge to learning, Mortimer (1995) tried to clarify the process of conceptual change by explaining how an individual's conceptual profile changes. According to his model, it is possible to think in different ways in different domains. In constructing meaning, he further states that accommodation of previous conceptual frameworks in the face of new information is not always necessary and may sometimes happen independently of previous conceptions. Vosniadou (2002) explained conceptual change as synthetic meaning or enabling one to gradually build conceptual models off of prior knowledge. On the other hand, Chi and Roscoe (2002) in discussing the processes and challenges of conceptual change interpreted a change in conceptual ecology as fixing misconceptions. They explain how wrong ideas are miscategorized and need to be recategorized into the proper conceptual places. DiSessa (2002), in writing about why conceptual ecology is a good idea, points out some difficulties with the "standard" model of conceptual change. He sees conceptual change as *knowledge-in-pieces* and explains that conceptual change is really about organizing fragmented, naive knowledge into intricate systems in the students' minds. A unique position was presented by Ivarsson, Schoultz, and Säljö (2002). They did not feel that naive conceptions played any role in the changing of someone's ideas. They felt that change in someone's conception is the "appropriation of intellectual tools" (Suping, 2003, p. 2). They perceive conceptual change from a socio-cultural view that occurs based upon the way individuals use intellectual tools in various social contexts.

Interesting enough, according to Schoultz, et al. (2002) human reasoning is tool dependent by nature. In a paper on the durability of conceptual change, Hakkarainen and Ahtee (2006) mention and interpret this finding as follows: “when children’s reasoning is supported by a cultural artifact (like the globe) they appear to be familiar with highly sophisticated modes of reasoning” (p. 464). An understanding of the various theoretical models of conceptual change is vital in course development. A common goal of any course designer should be to construct new courses that will maximize the potential of helping students reorganize their conceptual understandings. The course developed in this study will look to do this.

Conceptual Change Strategies

In regard to conceptual change strategies or overall plans which guide the sequencing of teaching within a particular topic, Millar (1989) notes that in practice there may not be a simple direct relationship between perspectives on learning and teaching strategies. Implications of the conceptual change model for teaching have been discussed in the literature first by Hewson (1981). Building from a constructivist’s viewpoint Hewson believes it is the teacher’s responsibility to be aware of students’ conceptions and to teach in ways that are likely to facilitate conceptual change on the part of the students. Teachers who take Posner’s et al. (1982) work on the four conditions that foster accommodation in student thinking as necessary for conceptual change must at the same time feel the conviction to adjust their instruction to meet these conditions. Nussbaum and Novick (1982) suggested a teaching process to facilitate conceptual change: the instructor (a) makes learner’s alternative frameworks plain to children, (b) presents evidence that does not fit their conceptual ideas and so induces dissatisfaction and (c)

presents the new framework, based on real science, and explains how it differs from previous anomaly. Further, Driver and Oldham (1986) proposed a five phase teaching outline to stimulate conceptual change. During phase 1 (*orientation phase*) the goal is student purpose and motivation. During phase 2 (*elicitation phase*) students make their ideas known through discussion or writing. Phase 3 (*restructuring phase*) consists of exposing students to conflicting views of other students and ultimately true scientific views via an evidence based teacher demonstration. Phase 4 (*application*) involves students applying their new conceptions in different situations. Finally, phase 5 (*review phase*) entails reflection of new conceptions. If Posner's (1982) work applies, students will be convinced that the scientific conceptions are more intelligible, plausible, and fruitful than their own conceptions. In an effort to review conceptual strategies Scott, Asoko, and Driver (1992) outlined two different groupings to conceptual change instruction. The first follows Posner's (1982) model and is based on cognitive conflict and the resolution of conflicting perspectives. The other groupings are of strategies which build on learners' preexisting conceptual ideas and extend them, through for example, metaphor or analogy, to a new domain. Subsequent teaching and learning involves the student in developing and extending these existing ideas towards the science viewpoint (Clement et al., 1987; Stavy & Berkovits, 1980).

A number of approaches constructed with the goal of teaching for conceptual change have used cognitive conflict as a foundation of development. The main focus of these approaches involves promoting situations where the student's existing ideas about some phenomenon are made explicit and are then directly challenged in order to create a state of cognitive conflict. Scott et al. (1992) describe that attempts to resolve this

cognitive contention provide the first steps to any subsequent learning. It is important to note that cognitive conflict strategies do not always lead to conceptual change (Lee et al., 2003). According to Hakkarainen and Ahtee (2006):

> When students' ideas are confronted with contradictory information through instruction, students may not at all recognize the conflict; or if a solution is proposed at a level which is beyond that of students it will remain meaningless to them and the effect of the conflict is lost; or sometimes the contradictory information can even be threatening to students who do not have enough knowledge to solve the conflict. (p. 464)

It is clear that strategies that implore cognitive conflict may not be effective when students do not have the foundational abilities to form better scientific ideas. Further, Limon (2001) states that the significance of a cognitive conflict must be apparent to students or the cognitive conflict strategy will fail. Significant learning can occur however, if the above is kept in mind regarding cognitive conflict. Kang, Scharmann and Noh (2004) discovered a significant correlation between discrepant event produced mental conflict and conceptual change. They state however, that cognitive conflict is only one event on the road to conceptual understanding and is not necessarily a prerequisite for conceptual change. Hewson and Hewson (2003) compared two instructional strategies, one building off of students existing knowledge including alternative conceptions versus a more traditional logical presentation as seen in most textbooks. This study which was done using high school students concluded that the experimental instruction strategy starting with student's prior conceptions resulted in a better acquisition of scientific conceptions and elimination of alternative conceptions compared

to the more traditional presentation of material. Hakkarainen and Ahtee (2006) proposed a learning-with-conflict model based on pupils alternative explanations about discrepant events. The students' explanations were then challenged with an event that was conflicting. When the learners saw and understood how the concept worked in different contexts it was possible for the students to reach a context independent conceptual change.

Conceptual Change Studies in Biology

Many studies to date have investigated conceptual change of biological misconceptions in the science classroom: photosynthesis (Griffard & Wandersee, 2001), ecology (Ozkan, Tekkaya & Geban, 2004), natural selection (Brumby, 1984) and genetics (Browning & Lehman, 1988; Fisher, 1985). Investigations looking at conceptual change of human physiology concepts include: diffusion (Odam & Barrows, 1995), enzymes (Rissing & Cogan, 2009), host-pathogen interactions (Marbach-AD et al., 2009), digestive system (Teixeria, 2000), respiration (Mann &Treagust, 1998), and the cardiovascular system (Michael et al., 2002). Many of these topics which hold misconceptions are interrelated and vital to understanding biology. A handful of studies have tried to pull some of these concepts together and eliminate misconceptions surrounding the unifying theme of human physiology called homeostasis. Assaraf, Dodick, and Tripto (2010) stressed system-based thinking as a way to address the conceptual change of homeostasis ideas in high school students. They found that high school students struggled with making the necessary connections to conceptually understand homeostasis. They stressed strategic scaffolding as a way to remove misconceptions and bring about conceptual change. Hung and Lin (2009) looked at junior

college students’ understanding of homeostasis. They found that conceptual change was hindered because of mistaken conceptual categorizations due to misconceptions. They suggested a focus on the number of body components involved and how they interact, an emphasis on the properties of emergence, mechanism type questions and good model presentations. Westbrook and Marek (1992) attempted to look at conceptual change of homeostatic concepts in the minds of students through a cross-age study. They investigated middle school, high school, and college level biology students and concluded that homeostatic misconceptions were similar and persisted all the way through the collegiate level even though college students were more familiar with homeostatic ideas. Alkhawaldeh, (2007) investigated conceptual change of human circulatory system concepts related to homeostasis of the human body. Results indicated that students exposed to methods of instruction that engendered conceptual change had better understanding and retention of concepts related to homeostasis than those taught under traditional instruction. Conceptual change texts were the instructional method of choice employed in this study. These texts focused on identifying and activating student misconceptions through examples that displayed challenging evidence which caused the students to ask questions.

Conceptual Change Instructional Methods

Fair amounts of instructional methods constructed to eliminate misconceptions and stimulate conceptual change have been developed. Suping (2003), whose work informed a portion of this section, has helped organize these methods. Tsai (2005) used ‘conflict maps’ as a way to promote teaching and learning. With the goal of challenging student’s misconceptions, the conflict map focuses on the use of discrepant events.

Further, computer-based interactions have been developed to stimulate conceptual change in students. In their research, Wiser and Amin (2002) recommend computer models along with verbal interactions and teacher scaffolding to bring about conceptual change. Mikkila-Erdmann (2002) in guiding students to accept conceptions, talked about the beneficial use of written questions and statements. Niaz, Aguilera, Maza, and Liendo (2002) suggest class discussions and debating to bring about conceptual change in students. Further, they suggest a focus on the history and philosophy of science to help facilitate learning. A final instructional method with the goal of stimulating conceptual change is inquiry-based instruction.

> As advocated by many science education reform documents, inquiry-based teaching may be seen as one strategy for teaching toward conceptual change, in that inquiry engages students in the exact same questioning of one's preconceptions and challenging of one's own knowledge that is characteristic of both conceptual change and scientific habits of mind. (Tanner & Allen, 2005, p. 113)

Regardless of the instructional method used, the goal is to bring students to the place where they actively and rationally replace existing prescientific misconceptions with scientific acceptable explanations (Alkhawaldeh, 2007).

Situated Knowledge and Related Assumptions

Subjectivity statement

I have been teaching higher education students for more than 15 years at various universities. Before this, I taught high school biology in both the public and private sectors. Being trained as a research scientist at both the undergraduate and graduate level has heavily shaped my thinking about quantitative research in the laboratory setting.

Furthermore, having an undergraduate degree in education and now earning a doctoral degree in education has helped me see the value of qualitative research, especially in the educational setting. My professional background and many of my personal experiences have shaped the way I view research and education in general. For the most part, my college experiences growing up entailed the teacher, who was considered the main dispenser of knowledge, dispensing information in a frontal teaching style. Students were expected to quietly take notes and ask questions when appropriate. When I started teaching college biology, I emulated the way I was taught as a college student. However, I started to realize that this was not the most effective way to teach life science.

I believe that non-major science courses, which I teach, should develop informed citizens who can think critically and equip students with practical knowledge that is relevant to their lives. Shortly after beginning my doctoral program and immersing myself in the literature, I began to see more clearly the benefit of inquiry-based teaching. This form of problem-based instruction is a good recipe for critical thinking and practicality. It was through the literature and further teaching experiences that I became convinced that traditional methods of instruction at the college level are usually not the most effective ways to teach. It is clear that a lecture format may work well in dispensing factual information but this type of teaching has not been shown to effectively bring about conceptual understanding (NRC, 1999). This journey has led me to my research interests and informs my study on how inquiry-based teaching as opposed to more traditional forms of teaching, impacts students in the college science classroom.

CHAPTER 3

METHODS

In this chapter on design and methodology, I will first provide a summary of the methodological approach used in this investigation. I will then introduce my participants and address selection, criteria and justification. Following this, I will do the same in introducing my choice of site for this research project. Methods and data analysis will then be addressed, at which point I will explore the measurement instruments used in attacking each objective in this study. The role of the researcher in a study is vitally important. Thus, I will discuss subjectivity and positionality as a strength and as a weakness in this research enterprise. Trustworthiness with monitoring strategies will be mentioned followed by study implications. These implications deal with ethical issues, risks and benefits, limitations and considerations that need to be taken into account. This chapter will be concluded with a discussion of how this research is significant and how it contributes to the knowledge base in the field of science education.

Methodological Approach

The methodological framework that drove this study came in the form of a mixed method study. Mixed method research has recently been presented as a third research paradigm in educational literature, third only to quantitative and qualitative research (Johnson & Onwuegbuzie, 2004). Creswell (2007) defines mixed method research as collecting, analyzing and mixing quantitative and qualitative research in a single study or

program of study. Johnson, Onwuegbuzie, and Turner (2007) say that:

> Mixed methods research is the type of research in which a researcher or research team combines elements of qualitative and quantitative approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the purpose of breadth and depth of understanding and corroboration. (p.4)

The type of mixed methods design that was employed in this investigation is called convergent parallel mixed methods design. According to Angell and Townsend (2011) this strategy employs separate quantitative and qualitative strands that eventually merge at the interpretation stage. Priority is shared equally in forming a more complete picture of the overarching question of the study. Both qualitative interviews, as well as quantitative assessment data were used in this investigation, to provide a broader perspective in trying to answer this overarching question. Offering statistical analysis along with qualitative interviews has helped this research to be more comprehensive in nature and has offset the weaknesses of either approach alone. The literature has spoken to this comprehensive benefit of the mixed methods strategy and this strategy is being employed more and more each year in educational research (Bryman, 2006).

"Action research happens when people research their own practice in order to improve it and to come to a better understanding of their practice situations" (Feldman, 2002a, p. 242). According to Kemmis (2009), action-oriented research aims at changing three things. These three things are practitioner's practices, their understandings of their practices, and the conditions in which they practice. There are many reasons why one would want to inquire into his or her own institution or, in this case, his or her own course. Glesne (2011) in quoting one of her student's reflections depicts the common

justification for choosing this methodological approach. This student writes, “Being able to choose my topic of interest situated in my passion, anchoring it to theory in which I am conversant, not only made it meaningful but also made it worthwhile for my institution and community” (p.43). For these reasons, and a strong conviction to evolve as a teacher, remain among the top motivations for choosing my own “backyard” as a research site.

Participant selection, criteria, and justification

The unique homogeneous sample or subgroup that was recruited to participate in the following project had a similar background of being a nontraditional, nonscience major, college student. However, these students were demographically diverse, of various socioeconomic status levels and were very diverse in age, ranging from 25 years of age to 50 years of age. It made sense to target this particular population of students because they have been neglected in the literature, and I have worked with this subgroup for over eight years, primarily in evening classes.

The National Center for Education Statistics (NCES) defines the traditional student as one who enrolls in college full time immediately after obtaining a high school diploma and works only part-time or does not work at all, relying on parents for financial support (U.S. Department of Education, National Center for Education Statistics, 2003). For the purposes of this study, any student who did not meet NCES’s definition of traditional student was considered a nontraditional student. The main reason why students enrolled in the eight week Biology 110 course was to fulfill one aspect of their general education requirements. I taught all Biology 110 night sections two nights per week for 4.5 hours per night during the course of the study. Each section consisted of 15-25 students; at least half were classified as nontraditional (Table 3.1).

Table 3.1: Breakdown of Participating Students from each of the Biology 110 Night Sections under investigation

Semester	Nontraditional Students	Traditional Students
Fall 2: 2012/2013	12/7	12/6
Spring 2: 2013/2014	13/10	12/8

Site selection, criteria, and justification

The subgroups of nontraditional students in this study were from a small, two year, suburban, undergraduate university in South Carolina. Each year, students who desire to take Biology 110 in the evening of the fall or spring decide on one of two sections offered, without prior knowledge of the teaching style of the course. Data were collected over four semesters from four sections with a total of 42 nontraditional students. The fall Biology 110 sections were taught with a lecture teaching style followed by cookbook lab confirmation (explain before explore) while the spring Biology 110 sections were taught with a guided inquiry lab style followed by student and teacher discussion (explore before explain). The lecture and cookbook approach to teaching was conducted during the eight week semesters of the fall of 2012 and 2013. The guided inquiry and discussion style of teaching was conducted during the eight week semesters of the spring of 2013 and 2014. Although guided investigations were more student centered and traditional approaches more step-by-step, each course was nearly identical in terms of the content covered, the amount of time spent on each topic, the materials used, and all laboratory investigations. The most prominent difference was the order of instruction employed by the teacher. Being the sole instructor for all classes under investigation allowed for consistency among the courses. It was this consistency that

served as a reasonable justification for selecting my own classes for the research project. Table 3.2 describes the typical class similarities and differences between the two contrasting courses. A major difference involved starting the inquiry class with a partially filled out concept map. Before class sessions began, prior knowledge was evaluated by asking students if they could make connections between presented terms. A major similarity, under the explaining phase, involved students sharing a few facts on relevant topics that I assigned them previously. Course comparisons are discussed further in the next chapters. All students worked in pairs and sometimes in larger groups during experiments.

Table 3.2*:* Typical class – Traditional Style versus Inquiry Style

Traditional Style (F12/F13)	Inquiry Style (S13/S14)
Engage Relevant News Clip	**Evaluate** Concept Map
Explain Frontal lecture on the topic at hand Students share on assigned topics Break/Snacks	**Engage** Relevant News Clip
Experiment <u>Cookbook Lab (Confirmation)</u> Question presented by instructor <u>Students</u> Create hypothesis Follow prescribed directions Share conclusions with others Answer post lab questions	**Experiment** <u>Guided Inquiry-based Lab (Explore)</u> Question presented by instructor <u>Students</u> Create Hypothesis Build own directions Critique one another’s directions Share and critique one another’s conclusions Answer post lab questions
	Break/Snacks
Extend (Real-World Visual) *Body Story* Clip	**Explain** Round Table Discussion / Lecture Students share on assigned topics
Evaluate Quiz Next Class	**Extend (Real-World Visual)** *Body Story* Clip
	Evaluate Quiz Next Class

All classes (fall 2012 / spring 2013 only) were video recorded to verify the intended teaching technique. The electronic quality of inquiry protocol (EQUIP) tool (Marshall, Horton, Smart, & Llewellyn, 2009) was used to assess and confirm the degree of inquiry-based teaching throughout the courses. EQUIP is a tool that has been used recently to assess the inquiry practices of middle school and high school teachers and to link their performance to student achievement. Over a period of three years, reliability and validity were established during the construction of the EQUIP tool (Marshall, 2009). More recently, Marshall, Smart, Lotter, and Sirbu (2011) in comparing EQUIP and Reformed Teacher Observation Protocol (RTOP) found both instruments "to be highly reliable instruments, both in terms of item reliability and inter-rater reliability." However, EQUIP was found to have stronger validity than RTOP for measuring inquiry-based instruction (Marshall et al., 2011).

Six topics related to homeostasis were chosen, and each topic was covered over one week. Biology 110 night sections run for eight weeks, meeting twice each week for a total of 16 classes. Four classes were committed to such activities as learning the rules, safety precautions, lecture and lab preparation and testing. A total of 12 teaching days in all were carried out. To establish inter-rater reliability, twenty percent of the videos of the various class sessions were EQUIP assessed by other EQUIP trained instructors. Below are the topics explored with both teaching styles in the different courses (Table 3.3).

Table 3.3: List of Major Themes that were covered over the Eight Week Semester.

Homeostasis & Biochemistry (Enzymes)	Homeostasis & Genetics
Homeostasis & Cells (Diffusion)	Homeostasis & the Cardiovascular System
Homeostasis & Microbiology (Bacteria)	Homeostasis & the Nervous System

Methods & Data Analysis

Measurement Instruments (Objective 1)

Objective: Does guided inquiry-based laboratory followed by student and teacher discussion bring about higher science achievement compared to lecture-based teaching followed by cookbook lab confirmation?

In addressing my first research question, the following measurement instruments were used: multiple choice pre and post-course tests and focus group interviews. Each will be discussed in detail below.

First, a multiple choice, two-tier, diagnostic test, with 40 questions, was used (Appendix 1). Some of these questions were extracted from various, published concept inventories constructed purposely to target biology misconceptions. Questions were chosen that tied into the course's overall theme of homeostasis. In developing the test items, the category of conceptual knowledge, along with several questions focusing more on the practices of science were taken into account. However, nature of science (NOS) questions was not included. Test items from published concept inventories (questions 1, 4 - 6, 7 - 9, 12, 15, 16) were modified to improve wording, and to "fit" the structure of the assessment. I created the other half of the questions. Questions on the subject of diffusion and osmosis (numbers 7 - 9) were extracted from Odam and Barrow (1995). Whole test reliability for Odam and Barrow (1995) was estimated to be .74 using the Spearman-Brown Formula. All other questions do not contain reliability or validity data. The creation of the two-tier diagnostic test made it possible to compare factual or recall question results (odd-numbered questions) with process-based question results (even

numbered questions). Data were analyzed to look for correlations in questions answered correctly and the type of teaching style under which students learned.

This test was given as a pre-test at the beginning of the eight week semesters before any teaching occurred, and then the same questions were embedded into the graded final exam. The embedded questions were then extracted to serve as a post-test for comparison with the pre-test results. Results of these tests were analyzed using the statistical tools provided by Microsoft Excel. In comparing the difference between the two treatment means, to find out if the average difference was significantly different from zero, an independent, two-sampled t-test was used. Microsoft Excel was more than capable of running this simple statistical bivariate analysis of the two variables. Further, pre-test means were compared between the different teaching style groups. The rationale here was that if these tests turned up statistically the same to each other, this would then show that the two groups did not differ in their initial knowledge. One could then move forward with effectively comparing the two groups.

A frequent goal of research experiments is to provide a “snapshot” of the population as a whole. Whatever population one is working with, it is important to remember that experimental “snap shots” are imperfect. Confidence in extending experimental conclusions to the entire population requires the use of statistics. Statistical tests are essential because sampling error exists even with well-designed experiments (Belk & Borden, 2007). Differences between the sample of a population and an entire population, called sampling error, occurs because if a population is variable, chance will always result in some difference between the sample and the population (Belk & Borden,

2007). Through the power of statistics, researchers can look at their sample data and determine how likely it is that their results are due to sampling error.

A test of significance often used in research studies is called the t- test or "Student's t" after William S. Gosset who published under the pen name "Student" (Moore, 2010). To put it simply, a t-test is a test to determine if there is a significant difference between two treatment means. A significant difference between two treatment means is usually indicated as having a p-value of less than 0.05 (Hampton, 1994). According to Moore (2010) "the probability that measures the strength of the evidence against a null hypothesis is called a p-value" (p. 373). The null hypothesis (Ho) states that there is no difference between the two treatment means (H_o: $\mu_1 = \mu_2$).

To obtain insight into whether students were interpreting the pre-test and post-test questions correctly, the test was administered in the spring of 2012 during a pilot run. This pilot semester also served to field test many of the inquiry-based exercises I was hoping to use in this study. Test administration was followed up with end-of-the-semester, focus group, interview questions based on the diagnostic test (Appendix 1). Students from the class section were asked to volunteer. Two volunteers were interviewed after grades were in for the semester. The interviews were videotaped and transcribed. Based on results from these interviews, six questions were removed from the diagnostic test because of lack of clarity or relevance to the overall theme of the course. Diagnostic test results revealed that questions 8, 14 - 17, and 19 - 20 (Appendix 1) showed, by the end of the course, considerable shifts in the class toward an understanding of the concepts presented in these questions.

During final exam week of the data-collecting semesters, but only after final grades were in, focus group interviews, based on the same test questions, were conducted with the students from the various biology sections (Appendix 4). Nontraditional students from the class sections were asked to volunteer. These interviews served to make sure students interpreted the questions correctly and to give more insight into the reasons behind students' answers to the various test items. The interviews were videotaped and then transcribed for analysis. The number of students involved in the various focus groups throughout this investigative undertaking ranged from five to nine students depending on how many volunteers were able to be recruited (Table 3.4). The times of the interviews are also indicated below in table 3.4.

Table 3.4: Breakdown of Focus Group Times and Participants from each of the Biology 110 Night Sections under investigation

Semester	Time of Interview (Minutes)	Nontraditional Students
Fall 2: 2012/2013	50/20	7/5
Spring 2: 2013/2014	50/20	9/6

Measurement Instruments (Objective 2)

Objective: Does guided inquiry-based teaching followed by student and teacher discussion versus lecture teaching followed by cookbook lab confirmation result in more positive attitudes toward science as a subject in school?

In addressing my second research question, the following measurement instruments were used: Assessing attitude toward science as a subject in school pre and post-surveys and focus group interviews. Each will be discussed in detail below.

To answer this question, an attitude survey created by Germann, (1988) was used (Appendix 2). Germann (1988) used descriptive statistics of four studies to determine reliability and validity of this survey. In all four studies, "Cronbach's alpha estimates of reliability were all greater than 0.95" (p. 696). Four statements out of the 14 were worded toward negative attitudes with respect to science. These statements were reverse coded in keeping with proper Cronbach's alpha preparation protocol. Microsoft Excel was used to prepare all Fall 2012 raw survey data. A popular software program commonly used by many education researchers called SPSS (originally, Statistical Package for the Social Sciences) was used to confirm this survey's reliability. All Fall 2012 raw survey data were transferred from Microsoft Excel to SPSS. Cronbach's alpha results using SPSS confirmed a greater than 0.7 reliability statistic at 0.93. This attitude survey was used as a pre-survey at the beginning of the semester before any teaching occurred, and then the same survey was conducted at the end of the semester for comparison with the pre-survey. The Likert scale was treated as quantitative so that an independent, two-sampled t-test could be used in data analysis.

To obtain insight into whether students were interpreting the pre-survey and post-survey correctly, the survey was administered in the spring of 2012 during a pilot run semester. Survey administration was followed up with end-of-semester, focus group interviews. The same volunteers that were interviewed in relation to objective one were interviewed after grades were recorded for the semester. The interviews were videotaped and transcribed. Based on results from these interviews, all survey questions were retained. Assessment results revealed that attitudes toward science as a subject in school after an inquiry-based science course were very positive. Questions 1, 7, 10, 13 and 14

(Appendix 2) showed a considerable shift in the class average, by the end of the course, toward a positive attitude of science classes. Interviews supported this conclusion.

During final exam week of the data-collecting semesters, but only after final grades were in, end-of-semester, focus group interviews based on the same survey questions were conducted with the same volunteers involved under objective 1 (Appendix 4). These interviews served to make sure students were interpreting the survey statements properly and to give more insight into the reasons behind students' attitudes toward science after learning through one of the two teaching styles. The interviews were videotaped and then transcribed for analysis purposes. Data were analyzed to look for correlations in attitude and student achievement.

Measurement Instruments (Objective 3)

Objective: Are nontraditional students' attitudes more positive toward learning through guided inquiry-based teaching followed by student and teacher discussion versus lecture teaching followed by cookbook lab confirmation?

In addressing my third research question, the following measurement instruments were used: Assessing attitude toward the style of science teaching pre and post surveys and focus group interviews. Each will be discussed in detail below.

A pre and post-survey that focused on determining students' attitudes toward a particular style of teaching was created (Appendix 3). This survey was used to give more insight into the reasons behind students' general level of satisfaction versus dissatisfaction with the guided inquiry/discussion style course as opposed to the lecture/cookbook style course. It was used, treated, and analyzed similar to the survey described under objective 2. Student interviews were also conducted in the same fashion

as described under objective 2. These interviews served to confirm survey statement interpretation and to give more insight into the reasons behind students' attitudes toward instructional method after learning through one of the two teaching styles. The interviews were videotaped and then transcribed for analysis purposes. Data were analyzed to look for correlations in attitude and student achievement. A Cronbach's alpha estimate of reliability was performed as was done under objective 2. However, no reverse codes were used. The survey statements were simply divided into two sets of statements. Eight statements were classified as traditional-style based statements and eight statements were classified as inquiry-style based statements. Cronbach's alpha was run separately on both groups of survey statements. Cronbach's alpha estimate of reliability threshold of 0.7 was exceeded by the inquiry-based statements at a 0.71. However, the traditional-based statement Cronbach's alpha results were at 0.50.

This survey was also pilot administered in the spring of 2012 and end-of-semester focus group interviews were conducted as described under objective two. Based on results from these interviews, all survey questions were retained. Pilot study assessment results revealed that attitudes toward the inquiry-based style of science teaching were very positive. By the end of the course, questions 4, 6, 8, 11 and 14 (Appendix 3) showed a considerable shift in the class average, toward a positive attitude with respect to inquiry-based teaching. Interviews supported this conclusion.

Measurement Instruments (Objective 4)

Objective: How do nontraditional students perceive an inquiry-based curriculum differently than a traditionally-based curriculum?

In addressing the fourth research question, focus group interviews were used. These interviews on attitudes were transcribed and coded in a similar fashion to what is described by Löfgren (2013). The coding schema was created through following the direction of Coffey and Atkinson (1996). The goal was to look for patterns in how nontraditional students perceived the inquiry-based curriculum differently than they perceived the traditionally-based curriculum.

First, once interviews were fully transcribed, they were quickly read through as a whole and general impressions were noted. Transcripts were then carefully reread, line by line. Certain parts of the transcripts were labeled or coded based on repetition, new insights, literature review confirmation, theory affirmation or something the interviewees stressed as important. The goal was to aim for a more superficial description of things. Ample phenomena were initially coded and then some were removed, recoded, or combined, once codes were grouped together to form themes. Working toward the abstract level, the themes were then labeled. The most relevant themes were retained and connected together into a coding schema. A diagram was created using Microsoft PowerPoint and was described under the results section. The connections depicted in the diagram are the main results of Objective 4.

Role of the Researcher

A good scientist consistently probes his/her research for potential weaknesses. From the onset of this research, I have pinpointed potential weaknesses and put into place preventive measures to address these. Three weaknesses were identified as concerns. The first deals with dishonest interview answers because of students' concern for good grades. The second deals with bias in selecting interviewees. The last one dealt with

making sure both contrasting courses were taught in the way they were intended to be taught. To increase the validity of my research, these weaknesses were monitored throughout this study using the strategies discussed below.

Monitoring strategies

The fact that this is a teacher-oriented (action) research project provides great strength and flexibility in countering some of the weaknesses above. In addressing the first weakness, all end-of-course focus group interviews were completed after final grades were recorded for the semester. Not only were students assured, prior to interviews, that grades had already been finalized, but they were also given their grades before the interviews began. The goal was to remove students' biased answers in fear that their responses might affect their overall grade.

Often, in an effort to please, research integrity can be compromised. Controversy stimulates negative emotions for me. I was concerned that controversial students who had valuable information to share might have been silenced in some way by my subconscious fear of controversy. For example, I might have been tempted to avoid asking certain students to volunteer for the focus group interviews because of the controversial way they share their views. This second weakness was addressed by selecting a diverse group of volunteers for all focus group interviews. Although not true random assignment, students with the highest grades in the course were mixed with students with the lowest grades in the course to make up the interview group. This was done by searching my gradebook for a few students who had an A in the course, a few students who had a B in the course, a few students who had a C in the course, and a few students who had a D in the course. In situations where I had multiple volunteers at a certain grade level, I purposely selected

certain students as to generate a more demographic and culturally diverse focus group. I believe this helped remove much of the influence of researcher bias in selecting students for the post-class focus group interviews.

This research project involved instruction with a more traditional approach toward teaching and compared it with inquiry-based ways of teaching. However, how could the quantity and quality of inquiry be measured to provide a true comparison between the contrasting teaching styles? To make sure that the inquiry-based teaching conducted in this research project was authentic inquiry, the electronic quality of inquiry protocol (EQUIP) was used as an instrument to analyze both contrasting courses. The EQUIP tool provides multiple raters (Time Usage, Instruction, Discourse, Assessment, Curriculum) that supplies not only individual indicator breakdowns but also supplies a holistic score regarding the level of inquiry displayed. It was intended that the two courses be clearly distinct. My constant goal was that the traditionally taught course be rated more toward pre-inquiry and the inquiry-based course rated more toward proficient inquiry on the EQUIP scales. Outside-trained instructors helped “EQUIP” random lesson videos from both courses to help identify any instructional bias. Because the pilot study for this research project was the first time I began to explore with inquiry-based teaching, this research project has also served as a crash course in inquiry ways of instruction. Being a novice in this form of teaching, I made a decision that I would try to focus on only some of the indicators for each category (instruction, discourse, assessment, and curriculum) of the EQUIP tool in the inquiry-based course.

Study Implications

Ethical issues

Just because researchers receive IRB approval does not guarantee that researchers will be ethical once they get into the field (Hemmings, 2006). Teacher (action) oriented research, like others forms of research, is confounded with ethical issues. Being a person of integrity does not exclude one from the innocent slights of ethical pitfalls. Three ethical issues that I needed to be aware of in my study involved reciprocity, compulsion and confidentiality. The old saying “take the data and run” is wrought with ethical issues. For the sake of this study, I defined reciprocity in terms of rewarding my research subjects for their time (Glesne, 2011). It was impossible to reward them equal to the benefits that I have received from this research project, but I made it my goal to not slight them in any way. For example, I did not give them less instructional time because of the need to do interviews. I kept my data collection classes consistent with my other Biology 110 classes. Furthermore, I did not put pressure on any of my students to participate in any of the interviews. Interviews were done on a voluntary basis only. Lastly, all data collected, especially including interviews, was held confidential through assigning anonymous numbers to students. All data write-up used student numbers instead of student names. All information collected was used for only evaluation of the research, and was not and will not be accessible by anyone other than the researcher.

Risks/Benefits

There were no known risks associated with participation in this research project other than some possible peer pressure during the focus group interview and peer confidentiality breach after the focus group interview. Possible benefits of participating

in the focus group interview included an increase in student content knowledge and knowledge of more student-centered instructional techniques. The information gathered from the focus group interview and other aspects of this research also helped inform and improve future science teaching in our state and across the nation regarding which teaching strategies have the biggest impact on improving the quality of science teaching and learning. Participants did not receive any monetary compensation for participating in any aspect of the study. Participation in the focus group interview or any other aspects of the research project was voluntary. Student grades were not affected whether they chose to participate or chose not to participate.

Limitations/Considerations

The research project at hand was an action research project with the major intent of improving my own biology teaching at the higher education level. It was not my goal to try to extrapolate these findings to all higher education life science classrooms. Neither was I trying to generate an all-encompassing theory on the most effective way to teach biology. I intend to share my findings but I will be careful to stress the uniqueness of this study to my pedagogical niche. This study had its strengths and weaknesses and needs to be treated contextually.

A limitation in a study that uses statistics might include sample size. The amount of subjects involved in a study often has a powerful influence over statistical significance. Efforts were taken to increase the sample size, thus bringing more validity to the study's results. The study was repeated during the 2013 / 2014 academic year. Data from both academic years was combined to increase sample size. Also, the survey used to address objective three was created by me as opposed to using a field tested survey as was used

under objective two. Cronbach's alpha numbers revealed that this newly created survey lacked consistency among the traditional based questions. This limitation was taken into consideration when addressing objective three. Further, limitations existed in the wording of the first three objectives in this study. In comparing the two contrasting courses, I used the wording traditional lecture and cookbook labs to explain the lecture before lab (explain before explore) style course. Guided inquiry where exploring preceded explaining was fairly clear, but traditional lecture and cookbook labs tended to be worded in a biased manner. This wording exuded negative feelings that made objectivity more difficult. It was not my goal to hide my biased feelings at the onset of this study but to make them plain. Turning the light on my bias toward inquiry-based ways of teaching, allowed me to openly address it and deal with it throughout this investigation. Bias did impact my study, but I explored monitoring strategies to help limit this bias. These strategies are described throughout his project.

Each year, students who desire to take Biology 110 in the evening of the fall or spring decide on one of two sections offered without prior knowledge of the teaching style of the course. Although recruitment of subjects in this way seems rather random, this is actually not true random assignment. Since an independent two-sampled t-test answers questions about the mean where the data are collected from two random samples of independent observations, the t-tests that were run in this study lacked full strength because of this weakness.

Significance/Contributions

This study is significant in that it is a first in exploring the differences between traditional and inquiry-based methods of instruction at the collegiate level in

nontraditional students. Although inquiry-based teaching has been shown to be very academically positive in science classrooms from K-12, “at the college level the data are mixed as to whether increasing inquiry instruction can significantly change students’ learning or attitude toward science” (Brickman, 2009, p. 3). To help delineate this controversy, more data were needed regarding the effectiveness of inquiry on student conceptual understanding and attitude toward science. Furthermore, little research has addressed student academic and attitude changes when entire college science courses are transformed from traditional approaches to more inquiry-based approaches. As opposed to just studying results from inquiry-based, isolated activities, how do students respond to an inquiry-based course versus a traditional, lecture-based course? Finally, some research has been conducted to help the academic growth of nontraditional students who are science majors (Deutch et al., 2008). However, research on how to improve the learning of nontraditional, nonscience major students taking science courses was absent from the literature. The purpose of this investigation was to address these gaps in the literature and to add to the knowledge base in the field of science education.

CHAPTER 4

FINDINGS

Making plans to conduct action research in one's own classroom can often be risky because the plans usually need to be in place well before class numbers are established. To further complicate this situation, if one type of student is the focus of the investigation then the research can be drastically hampered based on the numbers of the target population. Nontraditional students typically make up the majority of enrollees in our night section courses. Although this trend proved true in most cases during the duration of this study, nontraditional student numbers were still a bit lower than expected. To increase the number of nontraditional students in this investigative undertaking, the entire project was repeated the following school year. This additional data also helped to confirm trends seen in the first implementation of this study. Data from both runs of this exploration were merged together to provide a more complete picture of the insights that this project has revealed.

In this chapter, I will present the findings of this research project. As mentioned above, data from both academic year findings were combined. First, I will address objective one and reveal findings related to content achievement. An independent, two-sampled t-test was run to compare pre-test means between student pre-test results in the different style courses. An independent, two-sampled t-test was also conducted on the end-of-course content achievement to explore differences between differently taught students. Further, I will reveal the data that points to correlations in questions answered

correctly and the type of teaching style under which students learned. After this I will present insight from the EQUIP tool and display data that could be pulled out from this unique instrument. I will address results involving inquiry level assessment of both style courses and inter-rater reliability. I will conclude with focus group verification.

In this chapter, I will also present findings related to objectives two and three. Pre and post-attitude survey findings will be presented to compare the two contrasting taught courses in the area of attitude toward science and attitude toward style of science teaching. Results from the independent, two-sampled t-tests will be revealed and correlations between attitudes and student achievement will be presented for both objectives. I will conclude with Cronbach's Alpha results.

This chapter will end with heavy concentration on the focus group interview findings related to objective four. Focus group interviews on attitude were transcribed and coded in a similar fashion to what is described in Coffey and Atkinson, (1990). I will reveal coding results and patterns in how nontraditional students perceive an inquiry-based curriculum differently than a traditionally-based curriculum. This section will include a coding schema or a streamlined codes-to-theory model for this qualitative inquiry and validity results of the responses given on the surveys in this study. These interviews allowed me to probe for depth in the focus group setting to find out what students meant when they selected a certain answer of the Likert scale. This probing helped indicate whether different respondents perceived the question in reasonably similar terms, as well as what underpinned their reactions to it.

Quantitative Findings

Objective 1

The first objective of my dissertation research was to answer the following question: Does guided inquiry-based laboratory followed by student and teacher discussion bring about higher science achievement compared to lecture-based teaching followed by cookbook lab confirmation? A main goal of this research project was to determine whether the means of two populations on an outcome differ. For example, I compared two independent categories or two populations of students who received different treatments. I chose a two-sample t-test as the statistical procedure to compare the response variable of content improvement between my two unpaired groups of subjects. Weiss and Sosulski (2003) describes the two-sampled *t*-test as a hypothesis test that answers questions about the mean where the data are collected from two random samples of independent observations, each from an underlying normal distribution.

Hypothesis Testing

In the case of the study at hand, the null hypothesis (Ho) stated that there were no differences in average content achievement between the two comparison groups. In other words, the null stated that the difference between the means of both comparative groups was 0. On the other hand, the alternative hypothesis (Ha) stated the opposite. The difference between the two comparative groups was not 0.

T-test Results

Before comparing end-of-course differences, it was important to establish some kind of baseline. Pre-test means were compared between the different teaching style groups. All traditional style student pre-test scores together were compared with all

inquiry-based style student pre-test scores together. After running an independent, two-sampled t-test, these pre-test means turned up statistically the same to each other with a P-value of 0.26 (Table 4.1). A P-value of greater than 0.05 indicated that these results were statistically insignificant. Statistically, the two groups did not differ in their initial knowledge, which meant that the target objective between the two groups could then be effectively compared. This result is not surprising considering that when course style averages were compared, they were very similar (Figure 4.1).

Table 4.1: Comparing Pre-test Means between the Two Teaching Styles (Testing: H_o: $\mu_1=\mu_2$ against H_a: $\mu_1\neq\mu_2$).

Method for comparing means	t Stat	DF	Sig. P(T<=t) two-tail
Equal Variance assumed	-1.14	40	0.26

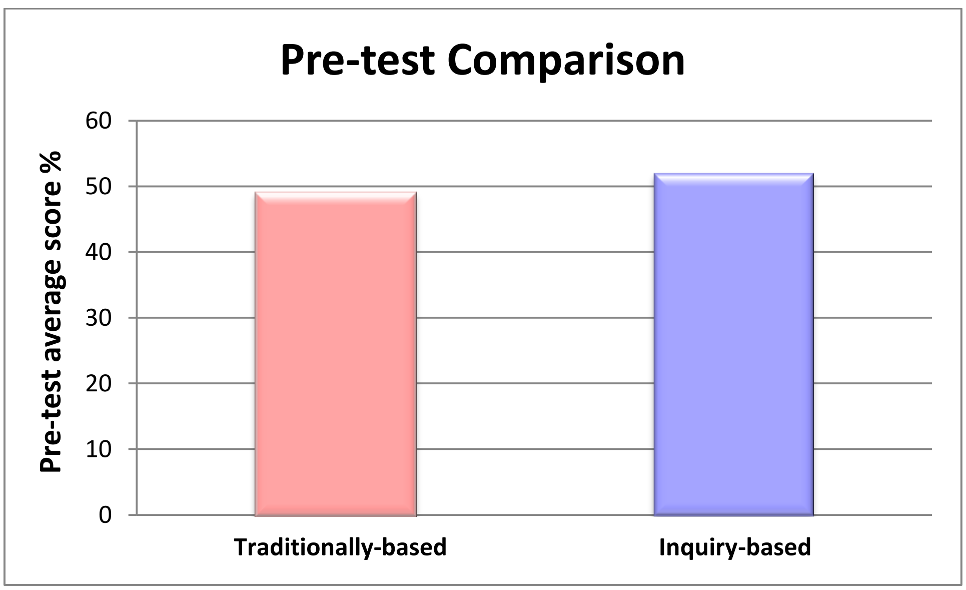


Figure 4.1: Comparing Pre-test Means between the Two Courses Under Investigation

The results following show the differences from the pre-test at the beginning of the semesters to the post-test at the end of the semesters. The traditional teaching style and the inquiry-based teaching style courses had 19 and 23 nontraditional students

respectively. The second academic year of data collection is in italics. No students showed a decrease in content achievement over the respective semesters (Table 4.2).

To picture more clearly the distribution of these numbers, a box plot was created (Figure 4.2). A main goal of boxplots is to display the center and variability of the data. Side-by-side boxplots are useful for comparing more than one distribution (Agresti, & Finlay, 2009). The box plot box contains the central 50% (interquartile range) of the end-of-course score increases from the lower quartile to the upper quartile. The lines across the boxes are the medians of the corresponding data and the asterisks are the means of the data. The vertical lines or whiskers extend from the maximum of 37 and 55 and the minimum of 10 and 0 for both courses respectively. Outlier tests revealed that no data points were to be considered an outlier.

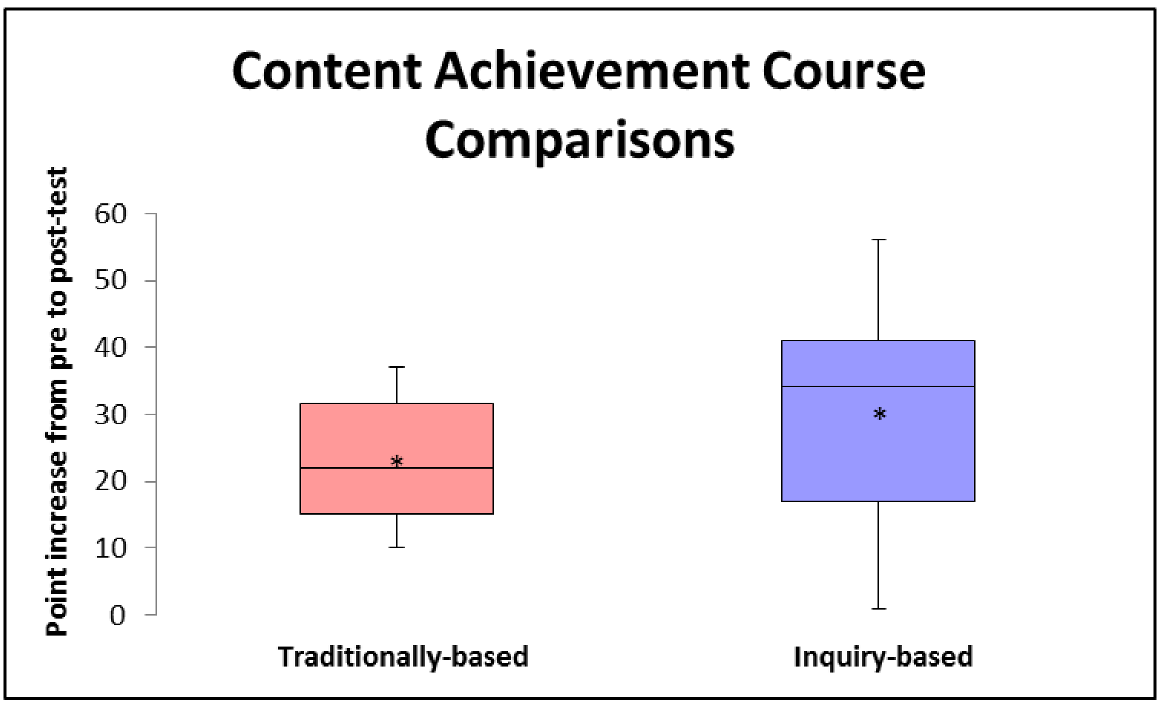


Figure 4.2: Content Achievement Course Comparisons

Table 4.2: Nontraditional Student Content Achievement over the Semesters

Traditional Course Student I.D.	Difference Pre to Post-Test	Inquiry Course Student I.D.	Difference Pre to Post-Test
2	22	1	20
4	18	2	55
6	28	4	40
8	23	5	40
10	33	6	5
11	10	7	10
12	22	8	10
16	37	12	38
19	15	13	0
20	15	15	35
24	35	16	35
25	23	17	40
		19	17
1	*10*	*2*	*25*
2	*20*	*3*	*45*
3	*15*	*5*	*35*
4	*12*	*6*	*33*
14	*35*	*8*	*23*
17	*33*	*9*	*5*
18	*30*	*10*	*40*
		11	*45*
		12	*15*
		14	*28*

When I compared the mean end-of-course pre to post-test differences between the two courses, the inquiry style course showed an increase over the traditional style course of almost five points (Figure 4.3 below). Does this mean that the inquiry-based style was a more effective style in producing content achievement? Not necessarily, because experimental “snap shots” are imperfect. Thus, we need statistic applications to help us determine if this difference really means anything. An independent, two-sample *t*-test was completed using Microsoft Excel. Table 4.3 below shows the results obtained. A P-value of 0.22 was acquired through comparing the content improvement differences between the courses taught with the traditional style to the courses taught using inquiry style. From a statistical standpoint, being more than 0.05 indicates that the inquiry teaching style was likely not more effective than the other in producing an increase in content achievement. In other words, there is a high probability, more than 22 in 100 (22%), that the two groups were different simply by chance. To put it simply, this test result shows statistical non-significance. I cannot reject the null hypothesis with over 95% confidence that the two treatment means are likely different. In fact, I am very confident of my null hypothesis that states that there was likely no differences in average content achievement between the traditional style taught courses and the inquiry-based style taught courses. I ran a confidence interval at 95% to gain more insight into this conclusion. This calculation further confirmed initial findings. Through running this test I was able to be 95% sure that the mean end-of-course difference between the traditional style and the inquiry style is between -3.1 to 12.7 points higher for the inquiry course than for the traditional course. The confidence interval contains O, further confirming the need to not reject the null hypothesis. Essentially this means that it is plausible, at the

95% confidence level, that the population mean change is O, that is, that the inquiry style does not result in any increase in content achievement over the traditional style.

Table 4.3: Comparing End-of-course Means between the two Teaching Styles (Testing: H_o: $\mu_1=\mu_2$ against H_a: $\mu_1\neq\mu_2$).

Method for comparing means	t Stat	DF	Sig. P(T<=t) two-tail
Equal Variance assumed	-1.12	40	0.22

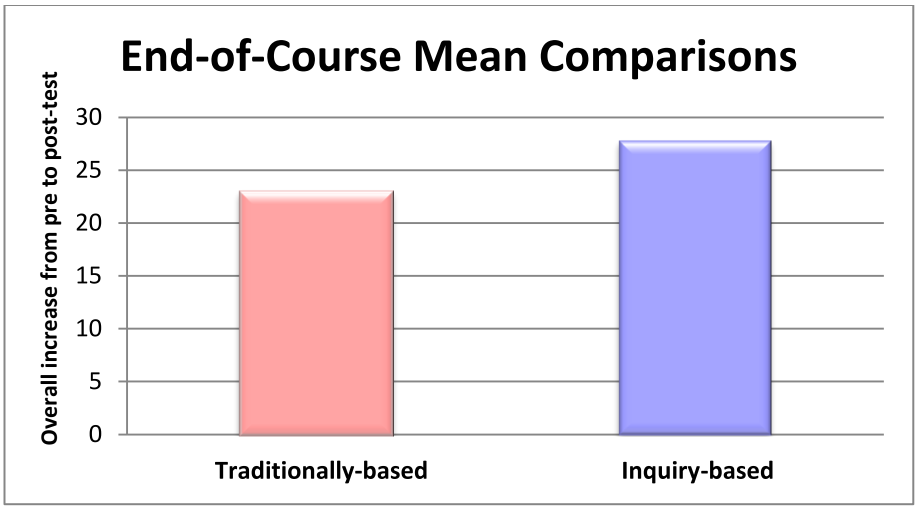


Figure 4.3: End-of-Course Mean Comparisons

The end-of-course pre to post-increase mean comparison was actually 4.8 points higher for the inquiry group over the traditional group (Figure 4.3). Is the estimated difference between the mean improvement score of 4.8 for the inquiry course large or small in practical terms? To answer this question I calculated this result's effect size. "A standardized way to describe the difference divides it by the estimated standard deviation for each group" (Agresti & Finlay, 2009, p. 200). The resulting effect size was 0.38. The difference between the sample means is less than half a standard deviation, a relatively small difference in practical terms. Actually, when pre-test score differences were taken into account, the difference was a bit smaller at around three points favoring the inquiry

course. Although this difference is small, on average the inquiry students did outscore the traditional students on the post-test (Figure 4.3).

Correlations in teaching style and correct test questions

Data were analyzed to look for correlations in questions answered correctly and type of teaching style under which students learned. In other words, the two populations were compared to assess if one population did better on certain types of questions compared to others. It became apparent that there was a clear difference when comparing the averages of the first six questions (Process of Science Questions) between the two style courses. On average, the traditional course students increased 9 percentage points from pre to post-test on these questions. However, the inquiry-based students increased 20 percentage points. When pre-test scores differences on the first six questions were taken into account, the differences between the two courses on these questions was seven percentage points favoring the inquiry-based course (Figure 4.4). An independent, two-sampled t-test revealed that these differences were just above the threshold of statistical significance, however the differences were clearly apparent.

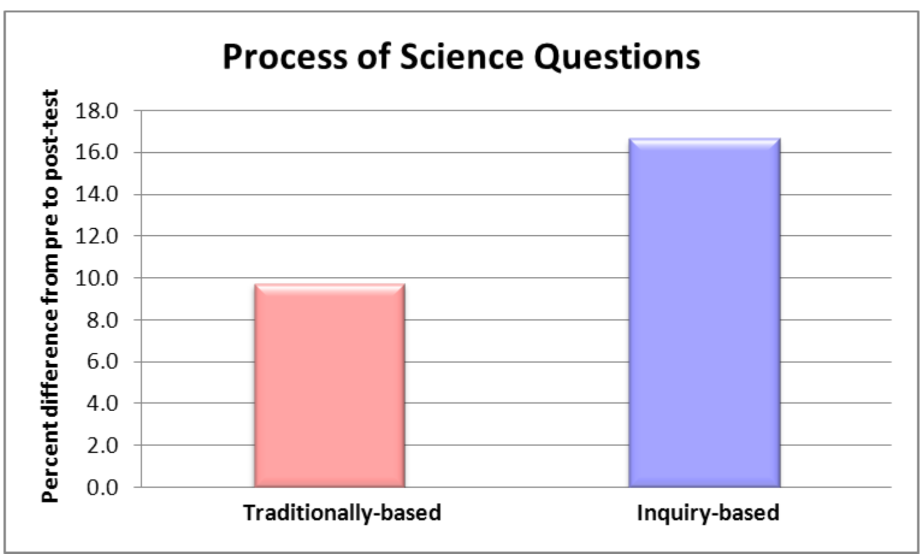


Figure 4.4: Process of Science Questions

When pre-test scores on the first six questions were compared with the corresponding post-test scores in the inquiry-based course using an independent, two-sampled t-test, the end result was statistical significance. A P-value of less than .05 at .048 was calculated. When this all was done with the traditionally-based course, the threshold of statistical significance was not reached. Factual or recall question (odd questions) average results between the two courses were compared with process-based question average results (even questions). After taking into account pre-test scores between the courses, it was revealed that the students in both courses scored relatively the same on the factual questions with only a one point difference favoring the inquiry-based students. However, on the process-based questions the inquiry-based students outscored the traditional-based students by three points. The trend of the inquiry-based group outscoring the traditional style group on process-based questions occurred 65 percent of the time. An example of this trend was seen early in the test on question number four. The previous question makes a true statement: In a scientific experiment, hypotheses are either rejected or supported (not proven). Students are asked if this is true or false. Question number four builds on this concept with a multiple choice question which asks the reason for this answer. Students are supposed to choose the answer that states that other factors (lurking variables) could affect outcomes. On this question, the inquiry-based student percentage point increases from pre to post-test, on average, was 13 points higher than that of the traditionally-based student percentage point increases (Figure 4.5 below). The opposite trend whereby the traditional style group outscored the inquiry-based group on process-based questions occurred 30 percent of the time. Process-based question scores on the remaining 5 percent were the same.

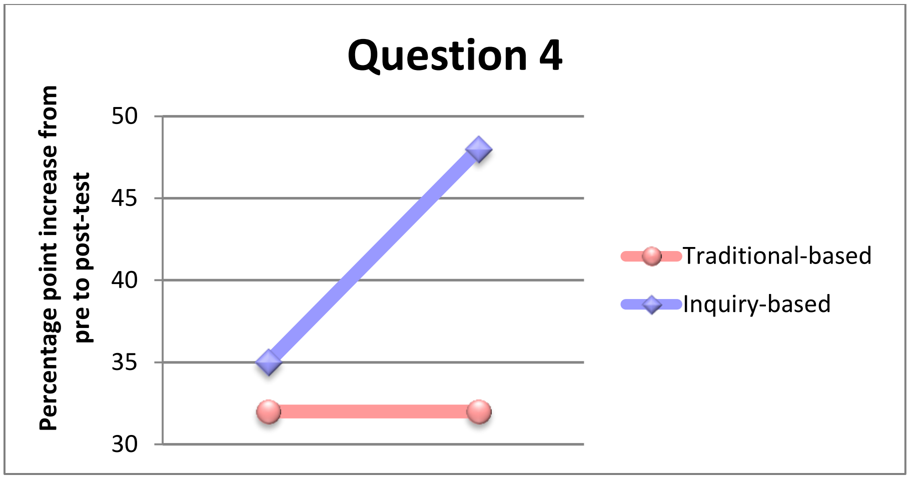


Figure 4.5: Question 4

EQUIP Evaluation

The quantity and quality of inquiry for the traditional Fall 2012 course and the Spring 2013 inquiry course, were measured using the electronic quality of inquiry protocol (EQUIP) tool. The purpose for presenting these findings is to show how the two contrasting courses differed in the level of inquiry-based indicators associated with each course. The Fall 2013 traditional course and the Spring 2014 inquiry-based course were not EQUIP assessed but were taught in the same way as the Fall 2012 and Spring 2013 courses respectively. The only difference was that some supplementary content was removed so that I did not feel rushed to cover as much material. Approximately twenty percent of the videos of the various class sessions were assessed by two fellow graduate students trained in the use of the EQUIP tool. Videos for the traditional style course and the inquiry-based style course for a randomly taught topic were chosen and given to these trained evaluators. One evaluator assessed videos on class session number five on cellular transport. The other evaluator assessed videos on class session number twelve on the body systems. On average both evaluators assessed the traditional style course around the pre-inquiry level (level 1) and the inquiry-based course crossing the threshold of

proficient inquiry (level 3). These evaluations served to help calibrate my evaluations as I was initially assessing slightly high for both style courses. The consensus after further collaboration with these other evaluators confirmed that the traditional courses on average should be rated closer to pre-inquiry and the inquiry-based course rated closer to proficient inquiry. This proved to be true when I personally reevaluated the additional 10 lessons encompassing 20 videos.

When all videos were EQUIP assessed, the data were transferred to Microsoft Excel. Evaluation numbers were added together and also averaged for each of the five instructional factor (Instructional Strategies, Instruction Order, Teacher Role, Student Role, Knowledge Acquisition) indicators separately for each class session taught under the traditionally-based style and taught under the inquiry-based style. For example, the first instructional factor indicator numbers for each of the 12 class sessions were added together and also averaged. These instructional factor indicator totals (not averages) for the two different courses were run against one another in a paired t-test. For example, the totals for the first instructional factor indicator for the traditional course was run against the totals for the first instructional factor indicator for the inquiry course and so forth. This same procedure was done with the discourse factor indicators (Questioning Level, Question Complexity, Questioning Ecology, Communication Pattern, Classroom Interactions), the assessment factor indicators (Prior Knowledge, Conceptual Development, Student Reflection, Assessment Type, Assessment Role), and the curriculum factor indicators (Content Depth, Learner Centrality, Integration of Content & Investigation, Information Organization & Recording). All but three paired t-tests showed results well below the threshold of statistical significance of 0.05. The forth discourse

factor indicator and the first and third curriculum factor indicators were above the threshold of statistical significance at .2, .1 and 1 respectively. When the totals of all the class sessions for all of the EQUIP factor indicators for each style course were averaged and run against each other in a paired t-test, the result showed statistical significance well below 0.05.

Average differences for each of the nineteen indicators between the two style courses were generated and used to create a bar graph (Figure 4.6). The inquiry-based course scored higher on all EQUIP factor indicators except for indicator number 18 (Integration of Content & Investigation) which was the same for both courses. This EQUIP factor indicator along with discourse factor indicator number 9 (Communication Pattern) and curriculum factor indicator number 16 (Content Depth) did not show statistical significance. Especially noteworthy differences between the two style courses were the second instructional factor indicator (Instruction Order), the first discourse factor indicator (Questioning Level), the third assessment factor indicator (Student Reflection) and the last curriculum factor indicator (Information Organization & Recording). These indicators showed a strong separation between the lowest level of inquiry teaching (Pre-inquiry) and the third level of inquiry teaching (Proficient Inquiry) (Figure 4.6 at the end of this section).

Several major adjustments were made to my Biology 110 course to make sure it had a strong inquiry influence when teaching it with the inquiry style. First, lab experiments were conducted before the formal lecture or discussion. This exploring before explaining emphasis became even more apparent when running the numbers on the EQUIP tool. As Figure 4.6 below shows, indicator number two (Order of Instruction)

showed a considerable difference between the two contrasting taught courses in this study. Further, the decision was made to not use cookbook directions with these lab experiments. Instead, students were to come up with their own plan of action or steps in attacking a preset scientific question or questions for each lab investigation. With proper modeling and scaffolding, I reasoned that students would not only become better with this each week, but that it would also cause them to think more about what they were doing during laboratory time. In most classes, students had to apply what they had learned in previous weeks about setting up proper controlled experiments. Approaching scientific questions with the challenge to apply the scientific method from hypotheses to conclusions is what caused such a high score above indicator number six (Questioning Level) (Figure 4.6). In addition, students were required to reflect on and discuss their plan of action with their lab partners and others in a cooperative learning atmosphere which I called the pair and share time. After discussing their plan with me, only then were they able to move forward with experimentation. This reflection challenged them to put more thought into what they were actually doing. This aspect of the inquiry-based course was also clearly seen within indicator number 13 (Student Reflection) (Figure 4.6). A pair and share time was also conducted toward the end of investigations so that lab partners could further discuss results with one another and communicate what they had learned with other groups. One goal of this pair and share time was to discuss how to organize their data since they were not given prescriptive ways of doing this. This aspect of the concluding pair and share time was evident in the high rating of indicator number 19 (Figure 4.6).

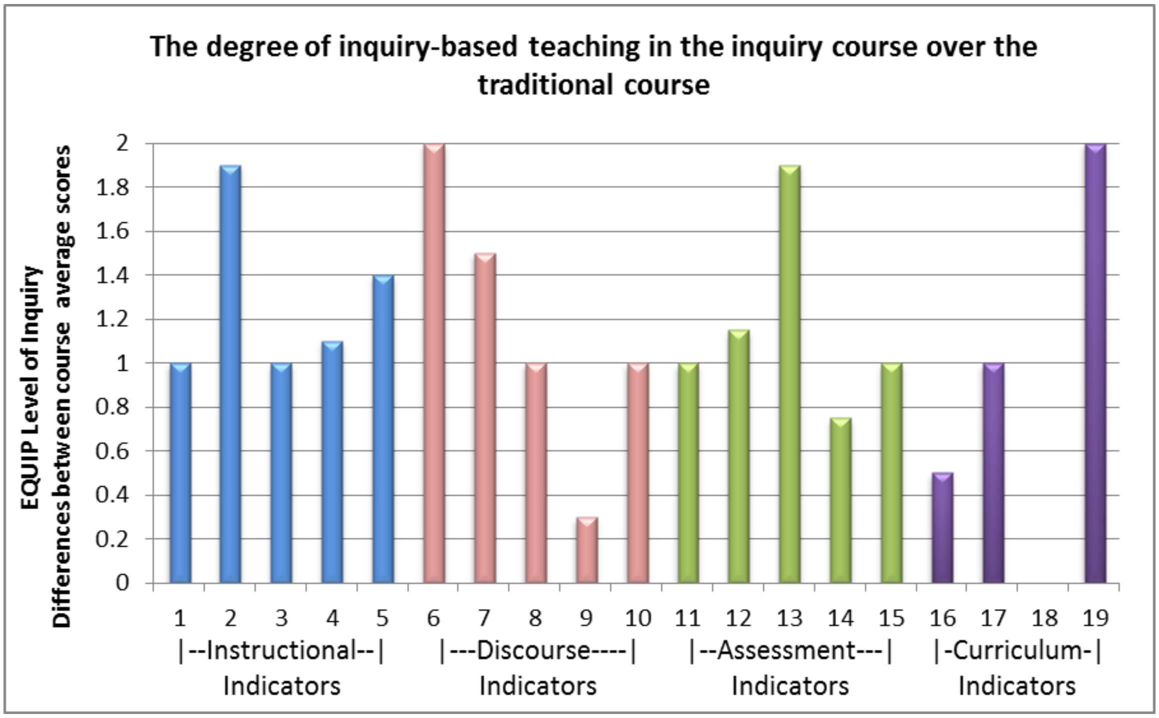


Figure 4.6: The degree of inquiry-based teaching in the inquiry course over the traditional course.

Focus Group Verification

During final exam week of the data-collecting semesters, focus group interviews, based on the same test questions, were conducted with the students from the various biology sections (Appendix 4). One purpose for the content portion of the focus group interviews was to verify that students were interpreting the pre-test and post-test questions correctly. Pilot study results indicated that forty of the forty-six questions of the original diagnostic test were appropriate regarding clarity and relevance. These forty questions were retained and used in this study. These interviews confirmed what the pilot study found; that the 40 questions in use were appropriate. Students seemed to interpret with accuracy a sample of the 40 test questions that were presented to them.

Objective 2

The second objective of my dissertation research was to answer the following question: Does guided inquiry-based teaching followed by student and teacher discussion versus lecture teaching followed by cookbook lab confirmation result in students with more positive attitudes toward science in school? To answer this question, pre and post-Likert scales were used in assessment. Many view the Likert scale as an ordinal scale (Knapp, 1990). It is often helpful to analyze ordinal scales by assigning numerical scores to categories (Agresti & Finlay, 2009). Thus, for the sake of this study, I treated the ordinal variables as interval so that I could explore the statistical summary of the average in examining this data. By using the methods available for quantitative variables, I was able to gain more insight into the results involved under this objective. Numbers were assigned to the different categories on the Likert scale with *strongly agree* being a five down to *strongly disagree* being a one. To find the sample mean, each possible value was multiplied by its frequency of occurrence. The total was then divided by the 19 responses (traditional courses) or the 23 responses (inquiry-based course) depending on which course I was analyzing. These numbers were then used to create a bar graph comparing survey question class averages (Figure 4.7). Negative attitudes toward science questions (statements) are indicated with an asterisk. A focus of attention was put on the degree of change from pre to post-survey in the traditional course versus the degree of change from pre to post-survey in the inquiry-based course. Inquiry style pre to post-increases (decreases with negative attitude questions) over traditional style pre to post-increases (decreases with negative attitude questions) were greater on every question regarding attitude toward science as a subject in school (Figure 4.7). Special attention was given to

the top three greatest changes between the different style courses. These three top changes came on questions focusing primarily on science interest (Figure 4.8). These questions were numbers three, five and six. This finding is discussed in detail in the next chapter.

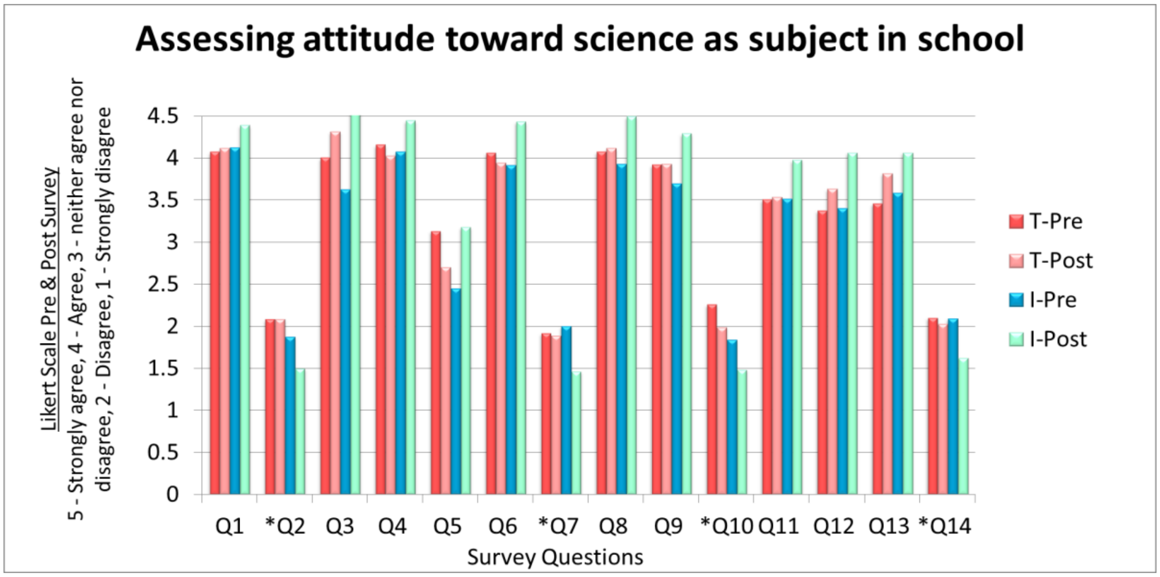


Figure 4.7: Assessing attitude toward science as a subject in school.

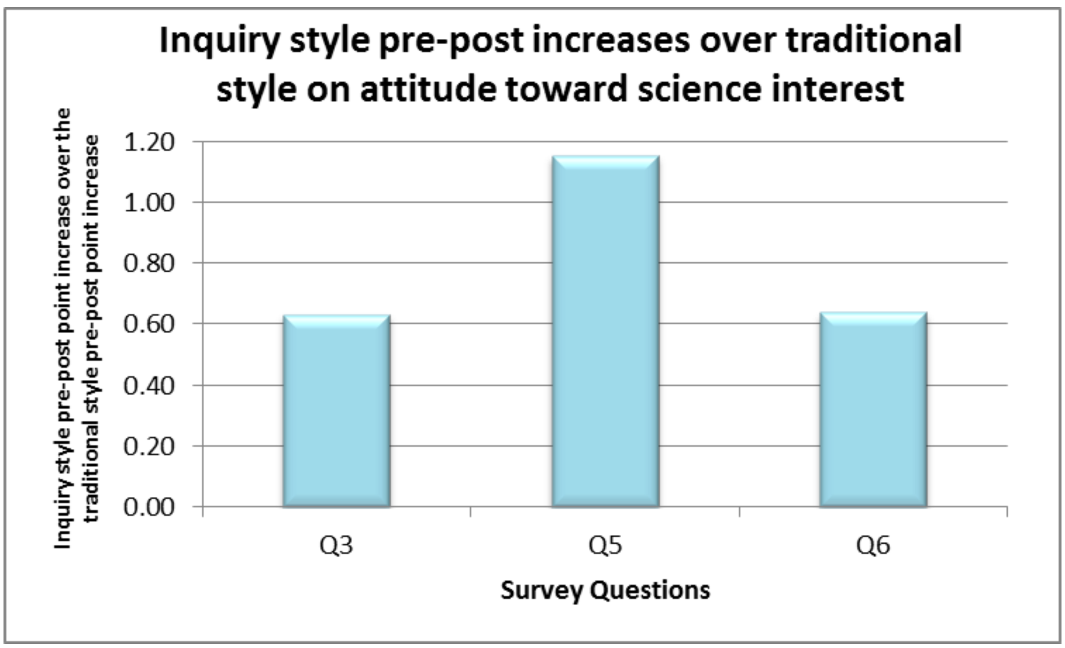


Figure 4.8: Inquiry style pre-post top three increases over traditional style on attitude toward science interest.

Positive and negative attitude questions toward science were separated and then averaged. In both cases, the change from pre to post-survey was more pronounced for the inquiry-based course as opposed to the traditionally-based course (Figure 4.9, 4.10).

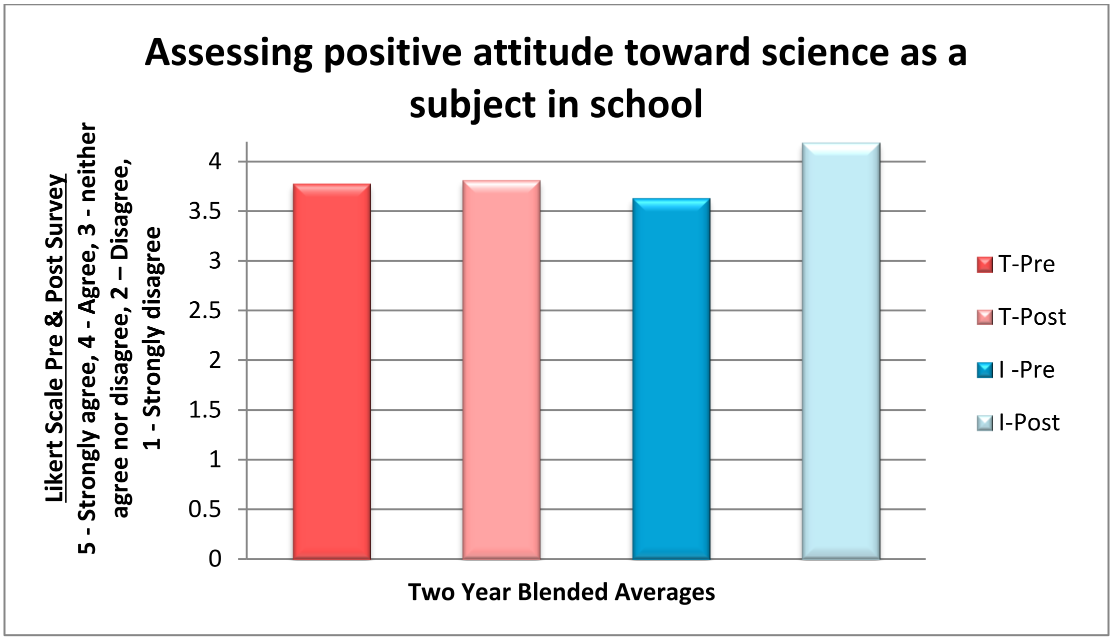


Figure 4.9: Assessing positive attitude toward science as a subject in school.

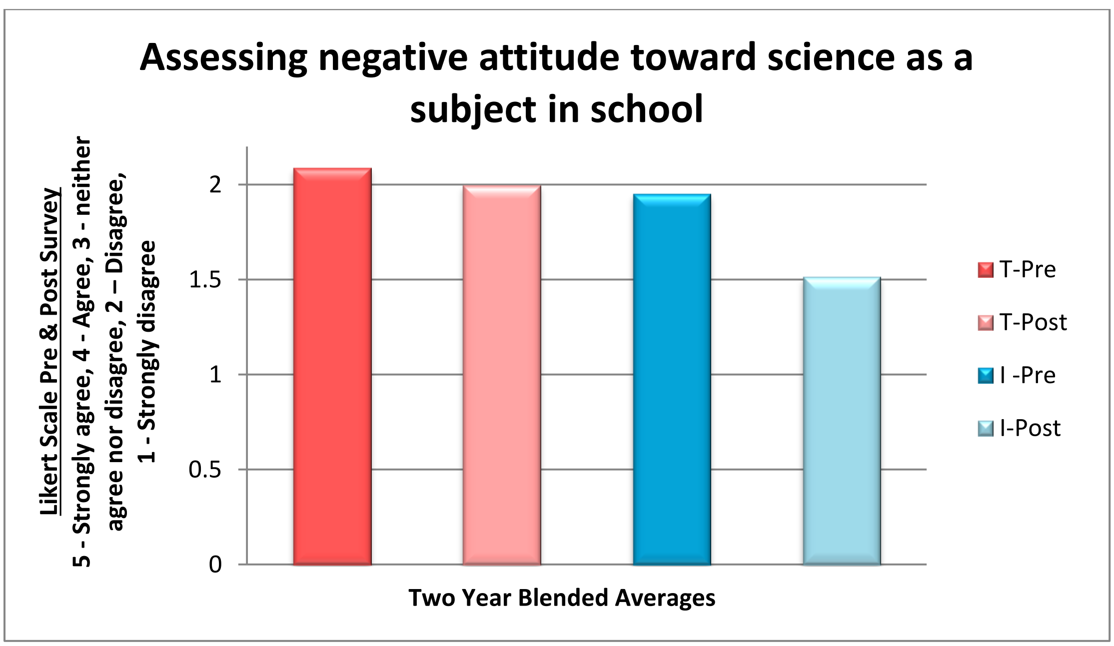


Figure 4.10: Assessing negative attitude toward science as a subject in school.

T-test Results

Treating the Likert scale as interval allowed me to run specific statistics. An independent, two-sampled t-test was run on the pre to post differences between the two courses using Microsoft Excel. All traditional courses' result averages for each question were run against all inquiry-based courses' result averages. Results indicated a P-value of 0.04. (Table 4.4). A P-value of less than 0.05 indicated that these results were statistically significant.

Table 4.4: Comparing pre-post survey averages on attitude toward science between the different style courses.

Method for comparing means	t Stat	DF	Sig. P(T<=t) two-tail
Equal Variance assumed	-2.03	54	0.04

Correlations in attitude toward science and student achievement

Data were analyzed in each of the two style courses individually to look for correlations in attitude toward science classes and student achievement. Four out of the fourteen statements dealt with negative attitudes toward science. These statements were reverse coded for consistency in addressing this objective. For each student, average attitude differences from pre to post-survey were calculated. Average student attitude differences over the semester, were compared with student increases on the course diagnostic test. After running statistical correlations with the data from both style courses, a weak relationship between the two continuous variables for both courses was revealed. The intensity of the relationship when addressing the possible connection between attitude toward science and achievement, showed a correlation coefficient closer to zero than negative one or positive one for both style courses. This same attitude data for each style course separately was divided into an upper and lower half to see if students with

the most positive attitudes toward science had higher achievement from pre to post-test at the end of the respective courses. The student with the median attitude score and corresponding diagnostic test score was removed to obtain an even number of students. It was revealed that the upper half of the students in the traditional-based course scored no different from the lower half of students in the traditional-based course (Figure 4.11). However, when the upper half and lower half were compared for the inquiry-based course, a clear difference was apparent. Students in the upper half who had the most positive attitudes toward science over the duration of the course exceeded the lower half by an average of five points from pre to post-diagnostic test (Figure 4.11).

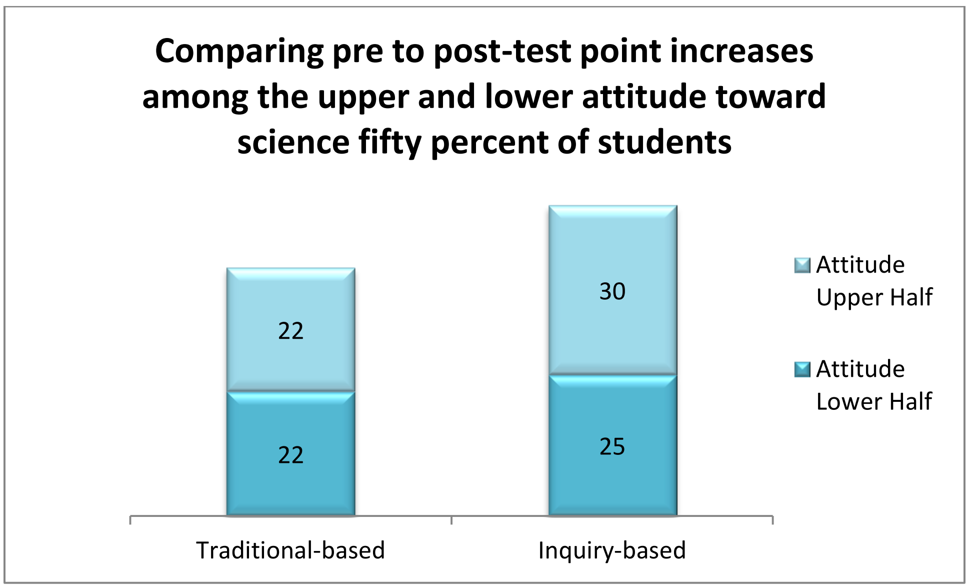


Figure 4.11: Comparing pre to post-test point increases among the upper and lower attitude toward science fifty percent of students.

Cronbach's Alpha

For this objective, Cronbach's alpha was run to see if results were similar to Germann's 1988 findings and ultimately confirm survey validity. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group (Nunnally, 1978). Negative attitude statements were reverse coded in keeping with

proper Cronbach's alpha preparation protocol. Germann (1988) used descriptive statistics of four studies to determine reliability and validity of this survey. In all four studies, "Cronbach's alpha estimates of reliability were all greater than 0.95" (p. 696). Cronbach's alpha results using SPSS confirmed a greater than 0.7 reliability statistic at 0.93, similar to Germann's 1988 results. A greater than 0.7 alpha is considered by many professionals to be desirable (Nunnally, 1978). Obtaining results over 0.7 meant that the attitude statements were reliable and could be used to effectively compare students' attitude changes from pre to post-test between the two contrasting taught courses.

Objective 3

The third objective of my dissertation research was to answer the following question: Are nontraditional students' attitudes more positive toward learning through guided inquiry-based teaching followed by student and teacher discussion as opposed to lecture teaching followed by cookbook lab confirmation? To answer this question, pre and post-Likert scales were used in assessment. In preparing all Likert scale data for examination, the scale was treated as interval as explained under objective 2. Under this objective, I focused primarily on the eight inquiry-based questions (statements). The reason for this is mentioned at the end of the reporting of the results under this objective. These numbers were then used to create a bar graph comparing survey statement class averages for each inquiry-based statement. Overall, students in the inquiry-based course showed greater increases on almost all inquiry-based statements over the duration of their course as opposed to the students in the traditionally-based course (Figure 4.12 below). Results for the last two statements (Q 14, Q 15) did not show this trend. Question 14 dealt with the desire to explore before explanations are given. Question 15 dealt with the

thought that learning occurs more when students set their own pace when completing independent or group projects. I propose explanations for these aberrations in the next chapter. Inquiry-based taught students showed pre to post-increases in positive attitudes on all but one (Q 14) inquiry-based statement (Figure 4.13 below). Students taught under the traditional style did not experience inquiry and thus served as a nice control. Survey overall averages on inquiry-based questions showed the traditional style group consistent from pre to post-survey whereas the inquiry-based group showed an overall increase (Figure 4.14 below). Interesting enough the inquiry-based group also showed a pre to post-increase on attitudes regarding traditionally-based statements. This aberration is also addressed in the following chapter.

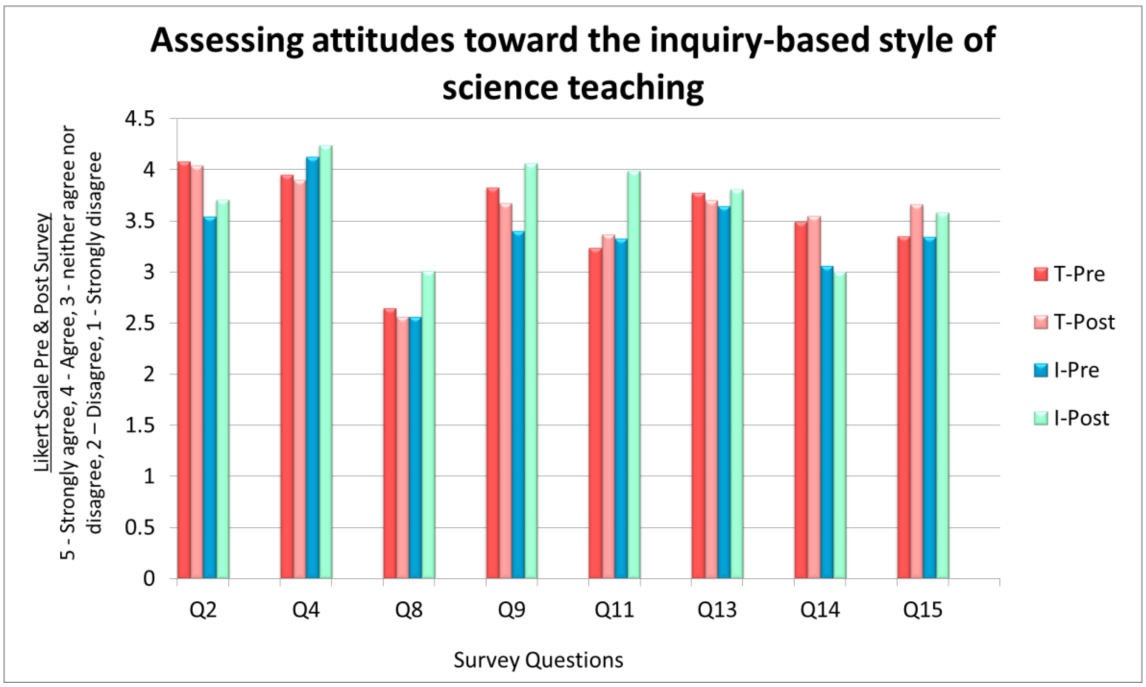


Figure 4.12: Assessing attitudes toward the inquiry-based style of science teaching.

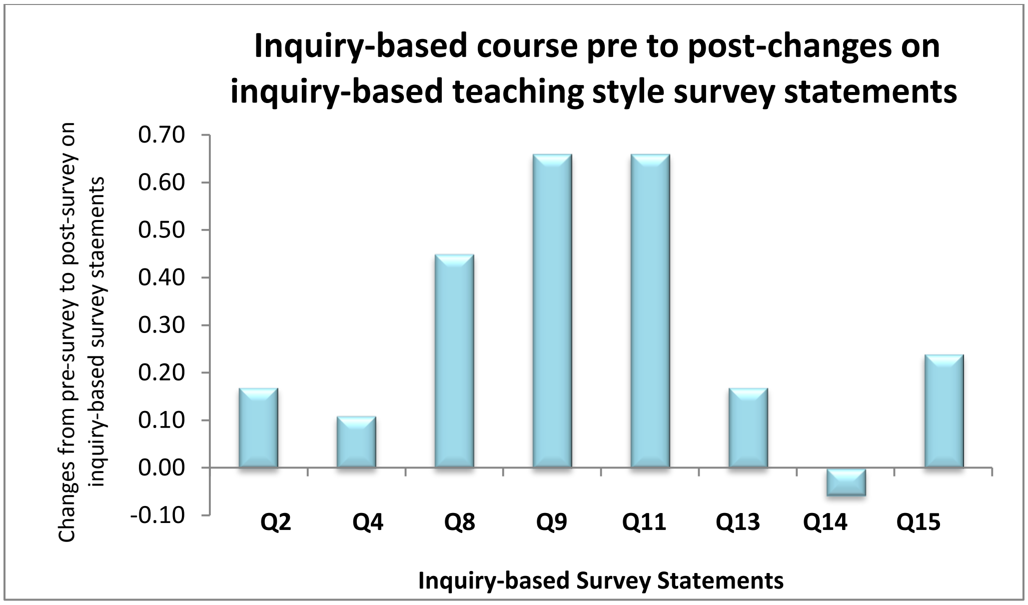


Figure 4.13: Inquiry-based course pre to post-changes on inquiry-based teaching style survey statements.

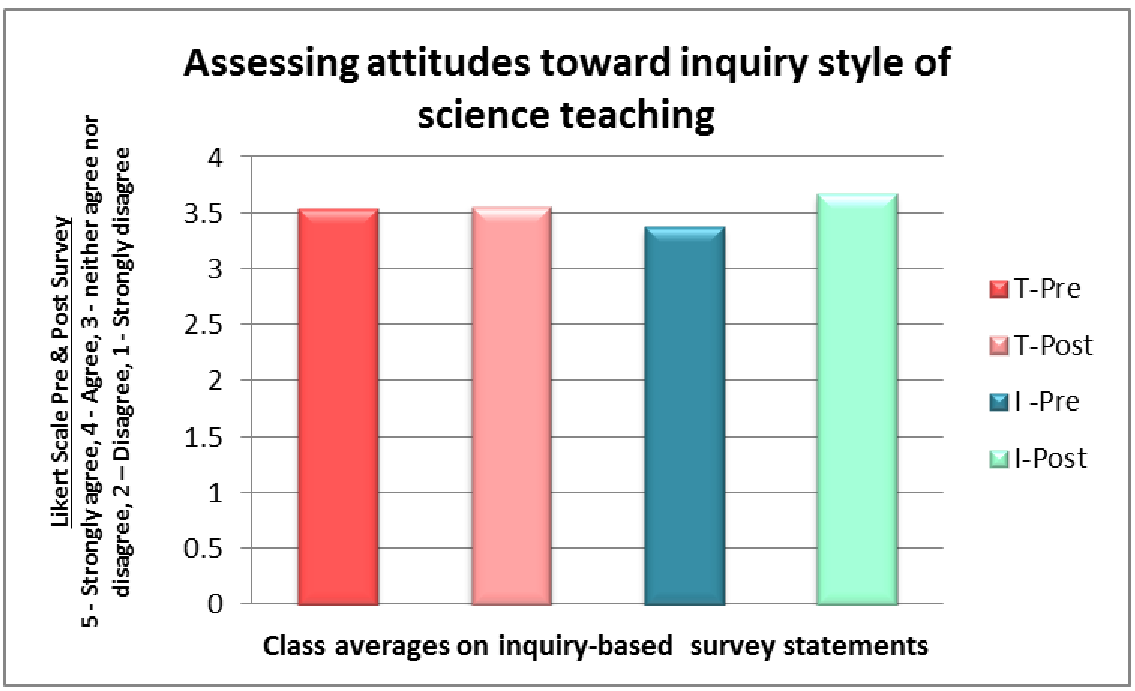


Figure 4:14: Assessing attitudes toward inquiry style of science teaching.

T-test Results

An independent, two-sampled t-test was run on the pre to post-differences from the inquiry-based course on the inquiry-based questions. I was interested to see if the

differences described above had statistical significance. All inquiry-based course pre survey results were run against all inquiry-based courses post survey results. Results indicated a P-value of 0.10. (Table 4.5). A P-value of greater than 0.05 indicated that these results were not statistically significant.

Table 4.5: Comparing pre-post survey averages on attitude toward teaching style between the different taught courses.

Method for comparing means	t Stat	DF	Sig. P(T<=t) two-tail
Equal Variance assumed	-1.68	30	0.10

Correlations in attitude toward style of teaching and student achievement

Data were analyzed in each of the two style courses individually to look for correlations in attitude regarding preferred style of teaching and student achievement. For both courses, the survey comments were divided into both traditionally-based statements and inquiry-based statements. For each student, average attitude differences from pre to post-survey were calculated for both traditionally-based statements and inquiry-based statements. Average student attitude differences over the semester, were compared with student increases on the course diagnostic test for both style statements. After running statistical correlations with the data from both statements from both style courses, a weak relationship between the two continuous variables for both statements in both courses was revealed. The intensity of the relationship when addressing the possible connection between attitude toward style of science teaching and achievement, showed a correlation coefficient closer to zero than negative one or positive one for both statements in both style courses. The traditionally-based and inquiry-based statement attitude data for the inquiry-based course was divided into an upper and lower half to compare inquiry-based student upper and lower half attitude differences with pre to post-test score differences.

The student with the median attitude score and corresponding diagnostic test score was removed to obtain an even number of students for both statements. Results revealed that the upper half of inquiry-based students who were more positive toward the inquiry-based statements increased more in score from pre to post-diagnostic test as compared to their counterpart lower half (Figure 4:15). When comparing the inquiry-based student upper half on traditional-based statements, it was revealed that this half showed a lower increase in score from pre to post-test compared to their lower half counterparts (Figure 4:15). It is worth mentioning that the upper and lower traditional-based statement attitude students in the traditional-based courses scored the same when comparing pre to post-diagnostic test differences. While on the other hand the traditional course upper attitude toward inquiry-based statements students scored four points higher from pre to post-diagnostic test compared to their lower half counterparts.

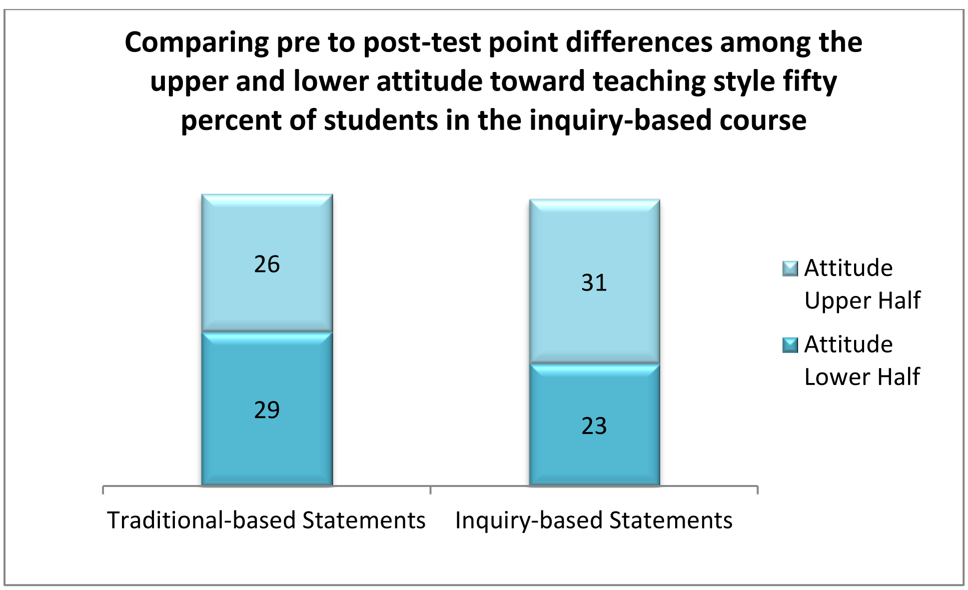


Figure 4.15: Comparing pre to post-test point differences among the upper and lower attitude toward teaching style fifty percent of students in the inquiry-based course.

Cronbach's Alpha

A Cronbach's alpha estimate of reliability was performed as was done under objective 2. However, no reverse codes were used. The survey statements were simply divided into two sets of statements. Eight statements were classified as traditional-based statements and eight statements were classified as inquiry-based statements. Cronbach's alpha was run separately on both groups of survey statements. Cronbach's alpha estimate of reliability threshold of 0.7 was exceeded by the inquiry-based statements at a 0.71. However, the traditional-based statement Cronbach's alpha results were at only 0.50. These numbers indicated that the inquiry-based statements were more reliable (exceeding 0.7) than the traditional teaching style statements. Because of this, traditional teaching statements were not a heavy focus of attention under this objective.

Qualitative Research Findings

Fall 2012/2013 Traditional Style Courses (Focus Group Interviews - Table 3.4)

On the last night of these classes I conducted a 20-50 minute focus group interview with a number of students who completed my traditional style (lecture followed by cookbook lab) Biology 110 courses (Table 3.4). I began the interviews asking if the students felt more negative or positive toward taking future science classes after taking my course. The consensus was positive for several reasons, with a first being confirming lecture and book material through immediate, practical, hands-on activities. Other reasons included appreciating my enthusiasm, demonstrations to confirm the concepts I was explaining, and my emphasis of understanding as opposed to rote memorization. Some of them complained about classes that focus only on lecture and reading the book. In building from my first question, I probed further with a question that asked their

opinions on how they felt science should be taught. Preferences included: mixing entertainment with learning, reasoning that it makes the material more memorable; introducing real life connections that students can relate to; and showing interesting video clips that initiate deeper analysis. Further, it was agreed that it is beneficial to use more simplified scientific vocabulary and good analogies to make the material more understandable, and the introduction of a course theme was seen as a way to organize one's thinking around the big picture. Probing even further, I asked the students to describe a past course format in which they felt they learned the most. Students shared that professors that used repetition through parallel reading, practical material, and online discussions, where students could discuss topics, assignments, and critique one another's material, were all helpful. Furthermore, one student shared the value of independent studies. Although my course did not have all these things, students reemphasized that my course focused on practical, hands-on activities which they mentioned was vital in past science classes as well.

This particular course was structured so that lab served as a confirming, reinforcing role for lecture material. In responding to the question of what they liked about the structure of the labs, they noted that the reinforcement of the labs was helpful and one student said he felt like a real scientist because of following directions, doing experiments and collecting data.

I presented a question regarding the sequence of the course. I said, "Does anyone feel they would like to do the lab before the lecture?" Several students responded that they would like this style. A few students agreed that this style would generate more questions, require more attention and make labs more interesting. Another student said it

might be helpful to learn through making mistakes. Others responded that this might be frustrating due to lab confusion and because students might be extra tired by the time the discussion rolls around. At this point student discussion veered off a bit and they began talking about what helped the lecture portion of the class. Comments were made that suggested the computer-generated mini-clips on concepts like mitosis or DNA added much to the lecture. Furthermore, a few students mentioned that comedy clips from popular movies that tied into the topic at hand were very helpful.

A question that I was very interested in having answered was: Have you experienced a science class where you were able to solve problems on your own, and, if so, how did you learn in this situation? Some students said that they did and that it was helpful. One other student said she had an enlightening, online class where she had to figure out ways to solve environmental problems. Probing further, I asked how they would like less direction during lab time. One student mentioned that she liked having labs that allowed for freedom to choose different variables. Most students mentioned that they liked balance between directions and freedom and they were optimistic about inquiry-based teaching if it was guided. Students in this style course had some opportunities to work in teams exploring questions with little direction from me. When asked how they felt about this they stated that activities like this teach you how to work with people. They mentioned that it was difficult for some because of disinterested classmates. Furthermore, they mentioned that a diversity of teaching styles is what they felt works best. An additional question regarding when students felt they learned the most revealed some interesting results. Students emphasized learning the most during the partially animated *Body Story* clips that I showed at the very end of class. These *body*

story clips are a part of a mini-series aired years ago. These clips combine real-life acting and computer-generated imagery. They show human body processes in our daily life in a docufictional style (The Discovery Channel, 2001). They shared how these clips were relevant, progressive, clear, impactful and made them want to share what they learned with their friends and family.

Students added much to my learning as an instructor of college science. In trying to wrap-up the interview due to time, I asked several questions from the survey they took, and I asked them to respond to those questions that piqued their interest. I call this the "interview popcorn wrap-up." The main purpose of this wrap-up was to get student survey confirmation in an oral form. In several final comments I learned that a number of students like to develop their own ideas about content instead of memorizing facts, although one student stated that concepts and facts lead to relatability. One student mentioned that if the exam is based on facts, then memorizing facts is vital to passing the exam. Another student said that she should be able to draft a personal narration of what she learned in the course as a way to evaluate her knowledge. In responding to a question about what was irritating about the lab exercises, students unanimously stated that when they had to do too many lab experiments in concession, it was frustrating. Also having a lackluster lab partner seemed to be a big annoyance because of the desire for fruitful discussions. One student mentioned having groups of three or four while another student mentioned rotating lab partners each week. Another question asked if learning occurs the most when students set their own pace for completing independent and group projects. Most said, "no" and expounded in saying that most students need accountability. Other students said that it depends on the person, and those with self-discipline might benefit

from this style of teaching. Yet another student mentioned the best way is to have projects broken up into sections with different due dates so that one can progress little by little. It was evident that most students appreciated an organized course blueprint with reasonable deadlines so that they could pace themselves.

Before I ended out the interview, I wanted to make sure I received student input in a few more areas. Regarding whether they felt they liked a step-by-step procedure or forming their own questions and designing their own investigations remained to be seen. Once this question was asked, it was revealed that many students were unwilling to abandon the cookbook entirely but were optimistic of a non-cookbook method and could see the benefits of the latter. One student felt the cookbook method produced more accurate data. Ultimately, they all agreed that guided inquiry would be the best if a course was taught in an inquiry-based way. To finish off the interview, I closed with, "Do you like lecture explanation followed by a lab to confirm what was explained to you, or do you prefer to explore and discover scientific phenomenon in lab before it is explained to you in a lecture?" Nine out of twelve said that they would prefer lecture before lab. Most revealed that they would fear entering the lab exercise with unanswered questions. These students said that they would be frustrated if they got stuck. A few students saw the potential benefit of such a style and mentioned the value of discovery and discussion.

Spring 2013/2014 Focus Group Interviews (Inquiry Style Courses - Table 3.4)

One goal on the final night classes of the spring of 2013 and 2014 was to repeat a similar focus group interview as was done with the fall night groups. Students in these focus groups completed my inquiry style (inquiry-based lab followed by class discussion) Biology 110 course. I began the interview asking if the students felt more negative or

positive toward taking science classes in general after taking my inquiry-based course. The consensus was that they have a more positive attitude toward taking future science classes. A common theme that emerged immediately and was mentioned throughout the interview was the relatability of the course material. Another early insight was the benefit of not using cookbook instruction for the lab exercises. Many students stated that this made them think more, which made overall understanding more concrete. One student said she felt like a real scientist because she had more control over the experiments. To further this, some felt that this learning came easier because of the pair and share discussions surrounding lab exercise, procedure building, and, ultimately, result critiquing. Many mentioned how they preferred the lab first, reasoning that it helped to get busy right away with hands-on activities after a long day at work. Further, one student felt that by having the lab first, he was able to process the material better because he was able to see it before learning about it. Another student commented that she is nosey and likes to know as much as she can before she does lab. After students shared a bit of why they have a more positive attitude toward science, I asked the group how they felt science should be taught. Many responded with the term “hands-on,” feeling application was vital to retention of knowledge. In all the courses in this investigation, I tried to connect what we were learning to a topic that could bring all the concepts together. The overall topic that I chose is called homeostasis. Homeostasis can be defined as: dynamic equilibrium of an internal environment. We began the course with this unifying theme of human physiology, connected new information to it as the course progressed and ended the course with this concept. Students appreciated this strategy in stating that building a connection with students through unambiguous topics and having an engaging course

theme is helpful to conceptual understanding. Demonstrations that stimulate discussions were pointed out and explaining a concept in multiple ways and from different angles was emphasized. One student mentioned the value of case studies and the desire to be challenged. All appreciated a personable, enthusiastic instructor who shares real life stories. I probed further and asked students how these main learning desires related to the course they just had taken with me. It became clear from student responses that the course they took with me contained what they felt made science teaching effective. However, a few students expressed frustration with the inquiry-based activities and creating their own lab exercise steps, stating that they like to be told exactly what to do. Although some were uncomfortable with this teaching style, they seemed to see the value of it, stating that it gave a sense of accomplishment and that it generated deeper thought. Enjoying the aspect of exploration and discovery, most felt that a guided inquiry style is the best approach and they also claimed that they became better at the inquiry-based style as the semester progressed.

A next question involved what they liked best about the lab part of the course. Many students mentioned, in a positive light, how the labs moved from easier to harder, as time progressed over the eight weeks. Time to explore was high on students' lists of lab time yearnings. Guided inquiry was emphasized with clear modeling, clues, and timely scaffolding to help alleviate any student fears. Students felt that they learned the most in the course during the post-lab discussions and the partially animated videos, especially the end-of-class *Body Story* videos. Other learning highlights mentioned were when they were able to make discoveries during the inquiry-based labs. For example, they used the microscope to discover atomic movement by looking at pollen grains in a

drop of water. Students were also asked to share one minute of information on an assigned chapter topic (student led mini-discussions) during the round table discussion part of each class. They felt that they learned much in preparing for this activity and also felt it was refreshing to listen to others. Being able to connect on Blackboard (course management system) with lab partners for cooperative learning was mentioned as an unfulfilled desire.

The second part of the focus group interview began when I asked students if they have ever experienced a science class in which they were able to solve problems on their own. Although most had not experienced this in the way they encountered it in this inquiry-based Biology 110 class, students emphasized the importance of having a good lab partner in navigating courses like this. Probing further, I asked how they felt when I started class by just giving them a question to solve. Some mentioned that although they still loved the course, they struggled at times with this aspect of the class and admitted that they went to other lab teams for help at times. They suggested that, for some lab experiments, groups of four might be better than two, reasoning that more minds would result in fewer struggles. Others felt using the problem-based approach to kick off class was great. They stressed that it generated curiosity and critical thinking. I then turned to the "interview popcorn wrap-up" (to confirm survey answers) and asked several survey questions, asking students to respond with whatever came to their minds. The first comment was, "Activities in class should allow students to form their own ideas about content." One student mentioned that when one discovers things and makes their own connections, the concepts stick more. Another student spoke up and admitted that although she was uncomfortable with not having step-by-step, that the inquiry-based style

did cause her to put more thought into what she was doing in class. The next survey comment asked if facts, concepts, and principles were the most important things students should acquire. Students felt this was important, reasoning that these things provide a foundation to critical thinking. One student felt that critical thinking does not need to be emphasized in school, concluding that it is a natural response that we all do throughout our lives. When questioned about if they are more comfortable with labs after this course, they responded, “yes,” feeling the experience they acquired in this style class removed a lot of lab fear. Students mentioned how they became less fearful as the course progressed and their experience with inquiry grew. Regarding the survey question about preferring a limited amount of guidance in lab, most felt this was desirable (with timely help) because it generated deeper understanding of the process required to reach an end-point in a lab experiment. As far as the question related to students setting their own pace for completing projects, all seemed to be in agreement that an organized outline was important. Many felt that Blackboard, our course management system, which I used, was helpful for this purpose and for posting notes. Further, they felt that reasonable deadlines are vital, and rigor balance is essential. One student stated that if the quantity of work gets overwhelming, the overall quality of her work goes down because she just ends up “throwing stuff together.” Nearing the conclusion of the interview, I asked students if they like a lecture-style of teaching with information dispensed to them, or if they like, better, exploring on their own with the teacher providing help as needed. One student felt that deeper thinking (exploring) leads to greater relatability and thus more retention. Another student appreciated the exploring because she felt it led to more student-to-student interaction. The conversation quickly steered to students appreciating the passion

I have for my subject but asked for more interesting and simplified news clips to engage students. When asked if they like the cookbook step-by-step labs or more like we did our labs, all students stated they liked the guided inquiry approach I used in class and one student emphasized that it was “freeing.” To finish off the interview, I closed with, “Do you like lecture explanation followed by a lab to confirm what was explained to you, or do you prefer to explore and discover scientific phenomenon in lab before it is explained to you in a lecture?” Eleven out of fifteen said that they preferred this new style of exploring in lab first as opposed to the traditional style of lecture and then lab. Reasons students gave of why they liked exploring first included the desire for immediate activity after a long day at work and the fact that labs serve as nice icebreakers. They also said that immediate exploration generated motivation, curiosity, hands-on activity anticipation, and the desire to develop one’s own connections. Further, immediate class interaction was mentioned as a desirable first activity of class. On the other hand, those who liked the lecture explanation first stated that they like to know exactly what they are doing and understand it before they dive into the lab. They had concerns with open inquiry. One student said he liked to save the best for last. Nearly all mentioned that guided inquiry is desirable, and most preferred mini-labs with discussion after each short experiment. They preferred this over long, uninterrupted lectures or long, uninterrupted labs. Students appreciated when lab was complimentary to the discussion topics.

Coding Schema

The coding schema below was created through following the direction of Coffey and Atkinson (1996). I looked for patterns in how nontraditional students perceived the inquiry-based curriculum differently than the traditionally-based curriculum. The most

relevant themes were retained and connected together into a coding schema. The connections depicted in the diagram are the main results of Objective 4 (Figure 4.16).

The coding schema was used to display, more clearly, student perceptions regarding an effective science curriculum. One group was viewing science curriculum through past science courses and through the lens of a present, traditionally-based science course in which they were enrolled. The inquiry-based students were viewing science curriculum through past science courses and through the lens of a present inquiry-based course in which they were enrolled. No matter what were the students past or present experiences, overall, they felt that a curriculum that initiates continual connection with students through relevant material is vital. A curriculum that is pertinent to real life, involves today’s animated computer technology, and is coupled with a thematic overtone seems to be very important to nontraditional college students taking nonmajor biology courses. Further, they appreciate interaction in their science courses that involves an enthusiastic instructor, group and class discussion rather than straight lectures, and reasonable accountability. Lastly, all students wanted application to be a major part of biology classes. Students generally agree that shorter lectures or discussions with shorter experiments are more helpful than long, uninterrupted lectures or labs. Student perceptions in the two different style courses deviate in that those in the traditional style course felt comfortable with sticking with more traditional forms of curriculum with cookbook labs and lecture before exploration. Students in the inquiry-based courses seemed to enjoy lab before lecture and embraced guided inquiry-based techniques as they experienced them over the semester. Nearly all declared that the extremes of too much lecture, or classes that are too open without timely help, are not

desires they would have in anticipating future science classes. This is new knowledge about how nonmajor, nontraditional college students perceive a traditional and inquiry-based introductory biology course (Figure 4.16 below).

Validity checks

These focus group interviews were also used as validity checks of the responses given to survey items. These interviews allowed me to probe for depth in the focus group setting to find out what students meant when they selected a certain answer of the Likert scale. This probing helped indicate whether different respondents perceived the question in reasonably similar terms, as well as what underpinned their reactions to it. Validity findings revealed that students seemed to have interpreted all survey statements correctly as was the case when piloting the surveys in the spring of 2012. Contradictions between survey results and interview responses did exist but were few. Some contradictory results existed regarding order of instruction and the amount of guidance students preferred during investigations. However, by pulling overall data together clear trends were able to be established. There will be more information on this when discussing objective four.

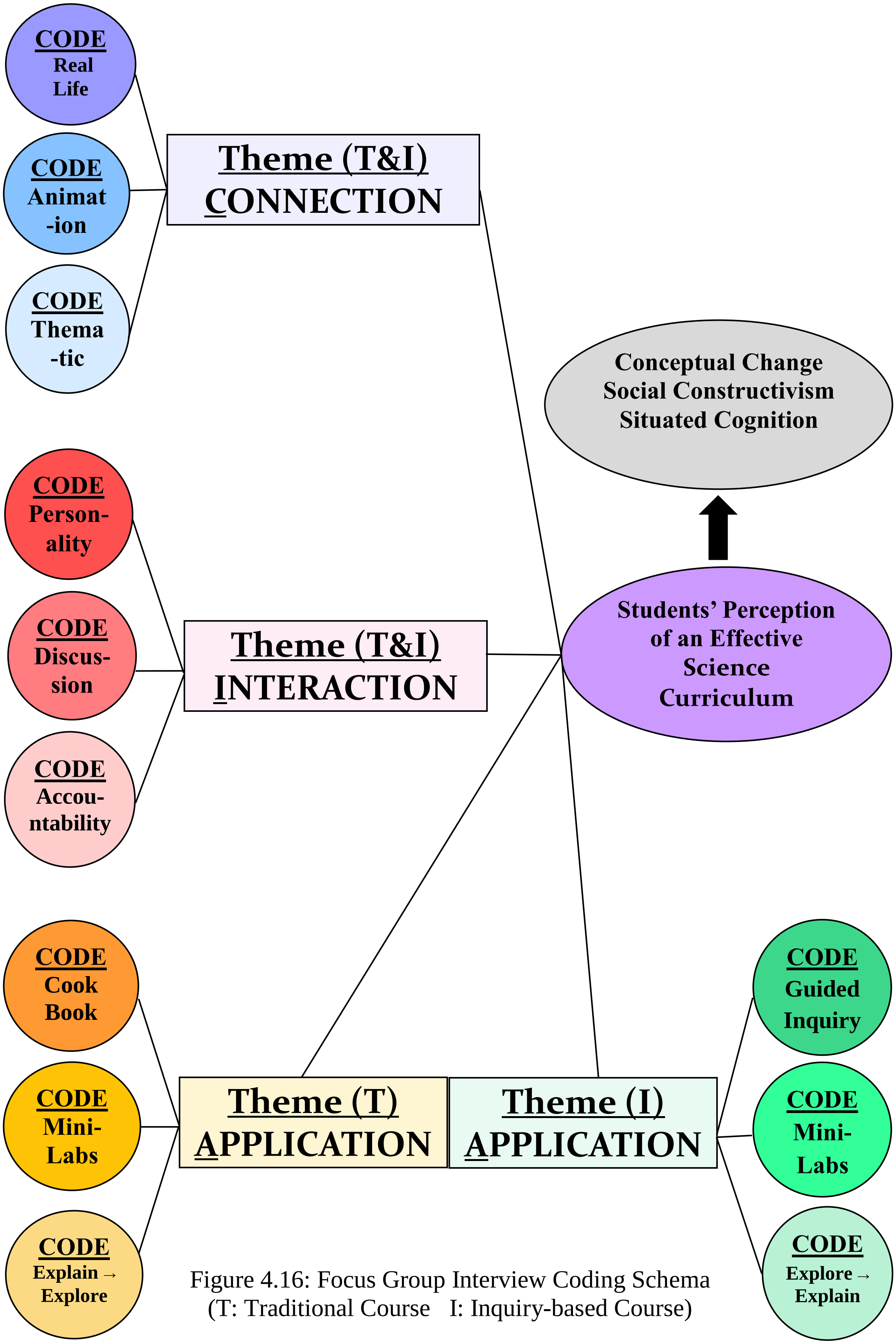


Figure 4.16: Focus Group Interview Coding Schema
(T: Traditional Course I: Inquiry-based Course)

CHAPTER 5

DISCUSSION

“And our schools must be the labs for learning about learning. Only if schools are run as places of reflective experimentation can we teach both children and their teachers simultaneously” (Meier, 1995, p. 202).

In this chapter, I will discuss results involving the four research questions under examination in this study. I will write out interpretations and discuss results in light of other published studies, theories or concepts from my field or other relevant aspects. Under objective one, I will discuss the content achievement results, especially the differences seen in the first six questions. Further, factual and process-based question comparisons will be discussed and the variability between the two contrasting courses addressed. Lastly, EQUIP results will be explained and test question verification mentioned. Under objectives two and three, I will discuss survey results and correlations between attitude and content achievement. Lastly, results from objective four will be discussed. The coding schema derived from the attitude portion of the focus group interviews and validity of the responses given on the surveys will be weaved into this discussion.

Quantitative Research Discussion

Objective 1

Descriptive & T-test Results

The first objective of my dissertation research was to answer the following question: Does guided inquiry-based laboratory followed by student and teacher discussion bring about higher science achievement compared to lecture-based teaching followed by cookbook lab confirmation? From a statistical standpoint, the evidence presented in this bivariate analysis indicates that there was likely no difference in overall student content achievement between the two different taught courses. Results indicated a P-value of 0.22 (Table 4.4). I ran a confidence interval at 95% to gain more insight into this conclusion. This calculation further confirmed initial findings. Through running this test I was able to be 95% sure that the mean end-of-course difference between the traditional style and the inquiry style was between -3.1 to 12.7 points higher for the inquiry course than for the traditional course. The end-of-course pre to post increase mean comparison indicated a score of 4.8 points higher for the inquiry group over the traditional group (Figure 4.3). I calculated this results effect size. The resulting effect size was small at 0.38. Actually, when pre-test score differences were taken into account, the difference was a bit smaller than 4.8 at around 3 points favoring the inquiry course. Had this study contained a significantly larger sample size, perhaps these objective one results would have been different.

Although inquiry-based teaching has been shown to be very academically positive in science classrooms from K-12, “at the college level the data are mixed as to whether increasing inquiry instruction can significantly change students learning or attitude

toward science” (Brickman, 2009, p. 3). These particular results discussed above do not help much in delineating the controversy regarding the effectiveness of inquiry to significantly improve college student overall conceptual understanding. These finding support the work of Nueby (2010) who found that grades in inquiry-based classes were not significantly higher than grades in standard lecture classes. However, inquiry students did outscore traditional students in both runs of this study and showed greater understanding on process-related questions, which will be discussed toward the end of this section.

Looking further into the data on pre to post-test content achievement differences between the two contrasting courses, intriguing insights were revealed. Boxplot results uncovered different distributions of the numbers between the different courses. The side-by-side depiction clearly showed that the inquiry-based style tended to be slightly higher and have greater variability (Figure 4.2). The reason for this difference in variability is unclear. It could just be random chance or this could be showing something unique about the inquiry-based taught students as opposed to the traditional style taught students. Perhaps the inquiry-based approach is embraced by and really helps some nontraditional students while others find themselves being more resistant to inquiry, resulting in a decrease of learning. Interviews certainly showed that not all students embrace inquiry alike but it remains unclear if these attitudes can be correlated with student achievement. Wallace et al. (2003) found that students with constructivist learning beliefs tend to add more meaningful conceptual understanding during inquiry labs than students with positivists or more traditional learning beliefs. Perhaps the variability of content achievement within the inquiry-based course has something to do with different learning

beliefs. If this is true then it might be helpful to teach about the nature of science. This might take the form of instructing students in the ways scientists think.

A reasonable question to ask when viewing the variability of the inquiry-based course scores in figure 4.2 is: Who are the students in the inquiry-based class who scored in the upper echelon of the boxplot and who are the students who scored in the lower echelon of the boxplot? For example, are traditionally low performing students benefiting from inquiry-based techniques? Further investigation needs to be done to tease out these details and address questions that delve into student content achievement and their demographic and cultural backgrounds. Perhaps insights can be gleaned regarding what types of nontraditional students benefit from inquiry-based teaching.

Correlations in teaching style and correct test questions

What about a connection between certain types of test questions answered correctly and the type of teaching style students learned under? The first six questions on the diagnostic test focus on the process scientists take (scientific practices) in trying to answer scientific questions (Appendix A). When taking pre-test scores into account, the inquiry group scored seven points higher than the traditional group on these scientific process questions. In fact the inquiry student results were statistically different from pre to post-test. This was not found to be the case with the traditionally taught students. In addition, when examining the entire test, inquiry taught students' outscored traditional style taught students by three points on the process-based questions (Appendix A). Is it possible that by avoiding cookbook directions in the inquiry-based course and having these students work together to come up with their own plan for experiments is the reason they did better on these critical thinking type questions? During the focus group

interviews one student even said: “when it’s *me* figuring it out, I know what process we did to get to that point, so I remember it more” (ICS13#4). When reflecting on the success of process-based question number four (Appendix A) one becomes more aware of the benefit of inquiry-based techniques. Factual or recall question number three makes a true statement: In a scientific experiment, hypotheses are either rejected or supported (not proven). Students are asked if this is true or false. Question number four builds on this concept with a multiple choice question which asks the reason for this answer. Students are supposed to choose the answer that states that other factors (lurking variables) could affect outcomes. Describing an inquiry-based lab experiment completed early in the courses should paint a clearer picture of why students who learned under inquiry seemed to do better on critical thinking process-type questions. In this example on the effects of thermal pollution, student pairs were presented a question: How does warm temperature affect amphipod (zooplankton) behavior? After generating a hypothesis, the inquiry-based course students were required to come up with their own directions on how to conduct an experiment to test their hypothesis. After the lab partners discussed their plan with those around them (Pair & Share) and I checked it to makes sure they were on the right track, they began the experiment. After the experiments were over, inquiry students shared their results with others and we all critiqued one another’s experimental setups and findings. On the other hand, in the traditional course, students followed cookbook directions in attacking their self-generated hypotheses. The setups were standard and findings were consistent, thus not much critiquing went on. It is reasonable to think that the extra steps and the extra effort required of the inquiry-taught students resulted in greater depth of understanding. In this example, inquiry students had

to think heavily about how to avoid lurking variables. A commonly shared critique over the semester involved the existence of lurking variables in the experimental setup up and its influence on quality results. Some even concluded that it was impossible to prove their hypotheses because of lurking variables. I propose that this forced analysis with the benefit of discovery (even at the expense of experimentation and error) over confirmation could be the reason the inquiry group outscored the traditional group on questions dealing with scientific practices (especially on question #4) and did better on process-type questions in general. These process-based learning increase results contribute to the findings of Wallace et al. (2003) and Brickman et al. (2009) among others, who showed that inquiry-based learning increases students' content knowledge of experimental biology and the process of science at the college level. Wallace et al. (2003) found that all the students in their study departed their course with a better understanding of the process of experimentation in science. They concluded that "there is potential for students to build conceptual understanding from inquiry-laboratory activities, although it appears that tighter instructional scaffolds may be necessary for some students" (p. 1021). In the Brickman et al. (2009) study students spend a considerable amount of time designing their own experimental setup, much like was done in the inquiry course under investigation. They found that student literacy regarding the process of science significantly increased, although student frustrations at times were apparent. This finding on frustrations was also reported in the study at hand. Further, Udovic et al. (2002) found significant content achievement differences favoring an inquiry course over a lecture-based course. In their study, one major finding was that students showed conceptual gains in the area of the scientific process. Written reflections confirmed this finding. Luckie et

al. (2004) in working with science majors, conducted a study in which they investigated the difference between traditional cookbook type labs with inquiry-based labs. In this inquiry curriculum: “student research teams pose a scientific question/hypothesis, propose an experimental design, perform multi-week investigations and then present their findings in various forms (web, interviews, and papers)” (p. 199). Students who learned under this teaching technique outscored their counterparts who learned under the traditional style, by an average of 10 points on a standardized Medical College admission type exam. These significant results were supported by qualitative data, which indicated that the inquiry lab curriculum based on the process of science or scientific practices, increases student learning. Although this test did not heavily emphasis experimental design, students who learned under inquiry still excelled under a more direct assay of content knowledge. Regarding reported student frustrations in inquiry-based situations, Gormally et al. (2011) stated:

> We believe student frustration with the process of struggling to ‘figure out’ how to address a particular scientific question was an indicator of success--truly engaging students with course content and offering a more realistic view of what it means to ‘do science’. (p. 48)

All these findings help support the goals of science education in creating a more scientifically literate society who can think critically and understands how real science works (NRC, 2012).

EQUIP Evaluation

T-tests results showed that although I never reached exemplary inquiry (Level 4) with the inquiry-based course, the courses were statistically different in the level of

inquiry. Only three of the 19 paired t-tests on the EQUIP indicators showed results above the threshold of statistical significance of 0.05. These were the fourth discourse factor indicator and the first and third curriculum factor indicators at .2, .1 and 1 respectively. All the rest of the indicators were well below the threshold of statistical significance. In fact, when the totals of all the class sessions for all of the EQUIP indicators for each style course were averaged and run against each other in a paired t-test, the result showed statistical significance well below 0.05.

Conducting inquiry labs before discussion, having the students' form their own procedures in trying to answer the question at hand and having frequent cooperative learning (pair and share) times were the most vitals aspects of the inquiry course. As described above, (Brickman et al., 2009; Luckie et al., 2004; Udovic et al., 2002; Wallace et al., 2003) a number of studies have shown the benefits of having students design their own laboratory procedures. As far as using problem-based activities before explanation along with cooperative learning, Knight and Wood (2005) used collaborative, problem-based mini-activities with positive results in their 2003 -2004 college courses. A portion of the lecture content was taught via inquiry-based activities with discussion instead of teaching all the material through straight lecture. What is relevant about this study is that these activities adequately replaced some of the lecture in teaching certain concepts. Students' actually understood certain content more through pair and share problem-based activities than when they learned this material through straight lecture.

It was these three aspects (exploring before explaining, student generated lab procedures, collaborative work) that were mostly responsible for making the two different style taught courses truly different and what made the EQUIP indicators so

different between the two courses under comparison. For example, the inquiry course activities were more than verification only. I was able to function more as a facilitator as students were more heavily involved in applying their knowledge in discussions and investigations. With these details of the inquiry course, it makes sense that all instructional indicators showed a difference in level of inquiry between the two contrasting courses (Figure 4.6). These big three not only impacted the instructional indicators but the discourse, assessment and curriculum indicators as well (Figure 4.6). Within discourse in high inquiry course classes, students were challenged with open-ended questions that required them to explain and justify their plans of action and their results from their experiments. Through integrating the big three into most lessons, I was able to assess learning through process-focused learning activities that required critical thinking. Having students set up their own controlled experiments served as a type of authentic performance assessment. Further, this flexibility for student-designed exploration was a vital curriculum indicator. All these distinctions of the inquiry-based course can be further verified from the EQUIP tool findings presented in figure 4.6. The inquiry-based course outscored the traditionally-based course in all indicators but one.

After lab investigations in the inquiry-based course, the goal was to open the floor for discussion based on the lab at hand. I did not do this very well because of the pressure to cover the same amount of content presented in the traditionally-based course. This pressure often pushed me into lecturing more than allowing for student and teacher discussion. This caused both style courses to be very similar when it came to communication patterns (discourse indicator #9). Two other areas in which the courses were very similar were a good connection to the overall course theme (curriculum

indicator #16) and making sure the content incorporated well with the respective lab experiments (curriculum indicator #18). These three areas can be seen as the lowest bars on figure 4.6. Besides giving a pre-test in both courses, in the inquiry-based course I did assess prior knowledge of the topic at hand at the beginning of each class but only did some adjusting of my instruction accordingly. This resulted in a moderate difference between the two courses (assessment indicator #15) (Figure 4.6).

According to Marshall (2009), a Level 2 on the EQUIP tool involves more prescriptive forms of inquiry and indicates that instruction is still heavily teacher-focused. Further, he declares that a clear aspect of Level 3 is that the teacher has established student-centered, problem-based investigations. At this point, the teacher is more of a facilitator. When examining the EQUIP results in more detail, it became apparent that on average I scored closer to a level three. It will be interesting to run this study again in the future when I become better at conducting inquiry-based lessons. Perhaps reaching an overall average of Level 4 (Exemplary Inquiry) will bring greater significance to a study like this.

Focus Group Verification

The main purpose for the content portion of the focus group interviews was to verify that students were interpreting the pre-test and post-test questions correctly. Students seemed to interpret a sample of the 40 test questions that was presented to them with accuracy. I did not have time to confirm proper interpretation of all diagnostic test questions. Almost half of the test questions were presented in the interview (Appendix D). This number seemed appropriate and I felt confident that interpretation of the questions presented was uniform from the pilot interview to the interviews conducted during the implementation of this research project. Content interview questions were not

asked during the second run of this study. The content section of the focus group interview could also have been used to give more insight into the reasons behind students' answers to the various test items. This aspect of the interviews was not fully explored.

Objective 2

Descriptive & T-test Results

> In order to recognize the importance of science, positive attitudes must be developed. It is the responsibility of each citizen to develop a positive attitude toward science. Here the role of the teacher in inculcating positive attitudes towards science is greater than any other individual. (Lakshmi, 2000, p. 4).

Attitude toward science classes can be defined as, "favorable or unfavorable feelings about science as a school subject," (Morrell & Lederman, 1998). A handful of studies at the collegiate level have found positive attitudes toward science in connection with the use of inquiry-based techniques in the science classroom (Berg et al., 2003; Burrows, 2003; Alouf & Bentley, 2003) while others argue against a connection (Kirschner, 2006). Berg et al. (2003) used an inquiry-based biochemistry experiment to look at student personal attitudes toward science teaching, learning and experimental work. Like as in this study, questionnaires and interviews were used in an action research project to compare two different ways of teaching a laboratory experiment, one being more traditional and one being more inquiry-based. A positive association between inquiry-based learning and attitudes toward science was noted. This study differed from this present investigation in that here I analyzed attitudes after an entire course of inquiry experiments. Burrows (2003) used a student-centered approach to teach general biology.

Much like the style of investigation in this study (Table 3.2), the two courses compared were different in teaching strategy. The control group was lecture-centered with minimal cooperative learning while the experimental group was student-centered with learning that was more cooperative. This study indicated an enhancement in students' interest in biology. Alouf and Bentley (2003) conducted a study whereby college instructors taught science elementary educators via inquiry-based techniques in a professional development program. This study showed a positive correlation between the use of inquiry learning and positive attitudes toward learning more about the process of science. College faculty modeled inquiry teaching to facilitate science educator content learning. Modeling was also used in the investigation at hand with positive attitude results. In doing a survey of the evidence at all education levels, Kirschner et al. (2006) explains why they feel minimal guidance during instruction does not produce positive results. They claim that minimal guidance produces "incomplete or disorganized knowledge" (p. 84). They take a strong stand against instruction with minimal guidance. They see inquiry teaching not supporting student overall positive attitudes toward science. The study at hand did not use minimal guidance. A guided inquiry approach, according to Brickman et al. (2009), was used to reduce student frustration levels, especially involving those who have never learned under inquiry before. The problem was presented and then students were guided in "selecting variables, planning procedures, controlling variables, planning measures, and finding flaws through questioning that helped students arrive at solutions" (p. 2). This study like the others mentioned above that showed positive attitude towards science after the use of inquiry, embraced the value of guidance when using inquiry-based

techniques. Further, lots of support for guided inquiry and its connection with positive attitudes toward science has come at levels below college (Foley & McFee, 2008).

As described above, (Berg et al., 2003; Burrows, 2003; Alouf & Bentley, 2003) the pro-inquiry data supports this study that adds to the weight of evidence that suggests that the use of inquiry-based teaching stimulates positive attitudes in college students toward science. Inquiry style pre-post survey increases (decreases with negative attitude questions) over traditional style pre-post survey increases (decreases with negative attitude questions) were greater on every question regarding attitude toward science as a subject in school (Figure 4.7). The message was even clearer when positive and negative attitude questions toward science were separated and then averaged. Pre to post-survey differences clearly favored the inquiry-based course (Figure 4.9, 4.11). In fact when all traditional courses result averages for each question were run against all inquiry-based courses result averages in an independent, two-sampled t-test, the result was statistically significant ($p<0.04$). From a statistical standpoint, the two groups did differ in attitude change from the beginning of the courses to the end of the courses. Two of the top three changes were on statements that dealt with science interest. Something about the inquiry course stimulated noticeable enthusiasm for life science in comparison to the traditional taught course. In fact, the greatest change involved a statement that dealt with the desire to learn more about science. Whether we are talking about elementary students or college students, the reasons are mostly the same for why student science interest is increased after an inquiry course. Inquiry-based methods stimulate natural curiosity and motivation for learning and connect science to the students' everyday life (Brownell, Kloser, Fukami, & Shavelson, 2012; Spencer & Walker, 2012). Brownell et al. (2012) conducted

a study on undergraduate biology lab courses. They compared the impact of a "cookbook" traditional style lab course with a research inquiry-based course in the area of attitudes. This inquiry course, like the course under investigation, had student determined experimental designs and collaboration among peers. This study found that research inquiry-based labs generate positive attitudes toward authentic investigation and increased interest in pursuing future research. "Rather than modeling how scientists develop and warrant knowledge claims, cookbook labs often reflect how well students can follow directions with little regard for the conceptual and procedural understanding of the investigation" (Brownell et al., 2012, p. 36). Students' curiosity for learning science was sparked by experiencing relevant scientific research. Although not empirical or focused toward college students, Spencer and Walker (2012) do a nice job describing inquiry-based instructional strategies as a method for generating student interest in science. They describe the 5E model (Engagement, Exploration, Explanation, Elaboration, Evaluation), the instruction strategy that informed this study (Table 3.2). From the engagement stage to the evaluation stage, curiosity is held paramount. It is what begins the scientific process and is what keeps the process going. Just as curiosity is a great learning motivator for young students, it can also be a vital aspect in the college science classroom. More of these things will be addressed when presenting and discussing student interview quotes under objective four. One quote is worth mentioning here: "I think before the class, when I came in, I thought I wanted more guidance, but I'm glad you did it the way you did. I liked how you put the words up there. It made us think. I mean, instead of just putting the answer there, before us, it made us wonder, "What *do* we need to do?" (ICS13#2).

Correlations in attitude toward science and student achievement

Data were analyzed in each of the two style courses individually to look for correlations in attitude toward science classes and student achievement. Although a strong relationship was not revealed when running statistical correlations with the data from both style courses, interesting findings were manifested when digging deeper into the results. Attitude results for each style course separately were divided into an upper and lower half to see if students with the most positive attitudes toward science had higher achievement from pre to post-test at the end of the respective courses. This was indeed the case for the inquiry-based taught students while not the case for the traditional-based taught students (Figure 4.11). Upper half inquiry taught students who had the most positive attitudes toward science over the duration of the course, increased by an average of five points from pre to post-diagnostic test. Perhaps the impact of an increasing positive attitude toward science in an inquiry-based course has a greater influence on content achievement. The literature does touch on this. Kazempour, Amirshokoohi, and Harwood (2012) explored students' perceptions of science and inquiry in a reform-based undergraduate biology course. The report on this qualitative study shares student quotes that indicate that those with the more positive attitudes toward science, feel they obtain greater conceptual stimulation through more open exploration in inquiry-based courses as opposed to lecture-based courses. This report indicates that the freedom experienced in the inquiry-based course may open the door for greater content achievement for many students.

> Students completed the course having gained (a) a better understanding of the process of scientific inquiry and the work of scientists; (b) critical-thinking, problem-solving,

> and science-inquiry skills; (c) a positive attitude toward science and inquiry-based science learning; and (d) a greater sense of accomplishment and confidence in their abilities to pursue science-related paths. (Kazempour et al., 2012, p. 42)

Further, studies at the secondary level, which is not extremely different from freshman science courses, have found similar results. Song-Ling and Chun-Yen (1998) looked at the impacts of an inquiry teaching method on earth science students' attitudes and learning outcomes. Quantitative data revealed that the inquiry-oriented instructional method produced significantly more positive attitudes and greater content achievement of earth science. Research continues in this area to establish a solid connection between inquiry course engendered positive attitudes and their impact on content achievement at the college level. The above research helps support my descriptive statistics that indicate that increasing positive attitude toward science in an inquiry-based course has positive influence on content achievement. Results from the study at hand, did not show a quantitative correlation in attitude toward science and student achievement. More quantitative data at the collegiate level is needed to support the qualitative work indicating that positive attitudes generated from inquiry-based classes cause an increase in content achievement. It makes sense that students love for science at all levels can be nourished and is more apt to flourish in an inquiry-based atmosphere. A common by-product of this is greater content achievement, especially in the area of the scientific process as was seen in this study and in Kazempour et al. (2012). "Active learning reflects the old saying "I hear and I forget; I see and I remember; I do and I understand" (Darling-Hammond, 2009, p.55).

Objective 3

Descriptive & T-test Results

As learning activities in the classroom become more inquiry-based and student centered, more meaningful learning takes place (Bonnstetter, 1998). Typically, when students learn, they appreciate the technique that stimulated such learning. In teaching nontraditional students for the last eight years, I have acquired a strong curiosity regarding the teaching style nontraditional students prefer to experience learning. Traditional style statement Cronbach's alpha results were at only 0.50. Being 0.50 put the traditional style statements in the poor category of internal consistency (Cortina, 1993). Because of this, traditionally-based statement results were not a heavy focus of attention under this objective. On the other hand, inquiry-based style statement Cronbach's alpha results were very positive. Thus, I focused findings primarily on nontraditional student attitudes toward inquiry-based techniques.

Overall, students in the inquiry-based course showed greater attitude increases and thus indicated a greater affinity toward inquiry-based techniques over the duration of their course as opposed to the students in the traditional-based course (Figure 4.12). The only exceptions to this were the last two statements, one of which is discussed below. This makes sense considering that the traditional group did not experience learning under inquiry and could only respond to inquiry-based statements based on prior experience. According to interview data, this experience was very little. Students in the inquiry-based course showed pre-post increases in positive attitudes on nearly all inquiry-based statements (Figure 4.13). The one statement that did not show this trend dealt with exploring before explaining. Interview results can explain this fear-based anomaly.

Inquiry taught students interpreted this statement as indicating no or very little pre-lab modeling or direction. When asked if they preferred exploring or lab with pre-lab scaffolding before the lecture or discussion, they embraced the concept of exploring before explaining. One student was quoted as saying:

> Yes guided inquiry! I just need to know a little about what I am about to do so I have an idea and then I can ask questions and get explanations about exactly what I am seeing while I do it. (ICS14#6).

Students taught under the traditional style did not experience inquiry and thus served as a nice control. Survey overall averages on inquiry-based questions showed the traditional style group consistent from pre to post- survey whereas the inquiry-based group showed an overall increase (Figure 4.14). The inquiry-based group also showed a pre to post-increase on attitudes regarding traditional teaching style statements. This interesting result likely stems from the same fear regarding minimal guidance inquiry just mentioned. It is reasonable that because of the fear of the possibility of being left without guidance in an inquiry-based situation, is what caused some students to hold onto a handful of traditional style teaching beliefs. As described earlier, minimal guidance may not be the most effective form of inquiry-based teaching (Kirschner, 2006). Guided inquiry (level 3 on EQUIP) however, has shown great promise (Brickman et al., 2009). In the guided inquiry approach the teacher presents the initial question to the students. Students are then guided through teacher questioning which helps students select variables, form hypotheses, generate procedures and ultimately critique findings (Magnusson, Krajcik, & Borko, 1999). According to Gormally et al. (2011) “Guided inquiry provides more direction to students who are unprepared to tackle inquiry

problems without support because they lack experience and knowledge or have not reached the level of cognitive development required for abstract thought" (p. 46).

An independent, two-sampled t-test was run on the pre to post-differences from the inquiry-based course on the inquiry-based statements. All inquiry-based course pre-survey results were run against all inquiry-based courses post-survey results. Results indicated a P-value of 0.10. A P-value of greater than 0.05 indicated that these results were statistically insignificant. Statistically, the two groups did not differ in attitude change from the beginning of the courses to the end of the courses. A clear trend does seem apparent however from the descriptive statistics discussed under this objective. More research is needed to see if this change indicates a real trend.

Correlations in attitude toward style of science teaching and student achievement

Average student attitude differences over the semester, were compared with student increases on the course diagnostic test for both style statements. After running statistical correlations with the data from both statements from both style courses, a strong relationship was not revealed between the two continuous variables for both statements in both courses. Looking more intensely into the data, the traditionally-based and inquiry-based statement attitude data for the inquiry-based course was divided into an upper and lower half to compare inquiry-based student upper and lower half attitude differences with pre to post-test score differences. Results revealed that the upper half of inquiry-based students who were more positive toward the inquiry-based statements increased more in score from pre to post-diagnostic test as compared to their counterpart lower half (Figure 4:15). This finding makes a lot of sense. Those who are more positive toward and prefer inquiry-based techniques learn more in an inquiry-based style course

compared to those who are more hesitant to learn under inquiry. I would not be surprised if these students who had more positive attitudes toward inquiry-based statements had more constructivist learning beliefs, while those who scored lower on inquiry-based statements had more traditional learning beliefs. If this is the case, then these results would support the findings of Wallace et al. (2003). They found that "students with constructivist learning beliefs tended to add more meaningful conceptual understandings during inquiry labs than students with positivist learning beliefs" (p. 986). When comparing the inquiry-based student upper half on traditional-based statements, it was revealed this half showed a lower increase in score from pre to post-test compared to their lower half counterparts (Figure 4:15). This finding further supports the above hypothesis regarding learning beliefs and success in inquiry-based courses. The students who were more pro traditional teaching techniques did not learn as much in the inquiry-based course compared to those of the lower half who were less enthusiastic with traditional-based statements. These results are tentative however because when comparing pre to post-test point differences among the upper and lower half attitude students in the traditional course, the results were the same.

Qualitative Research Discussion

Objective 4

In this section, I will discuss results involving the fourth research question. Focus group interviews on attitude were transcribed and coded in a similar fashion as that described in Coffey and Atkinson (1996). I diligently looked for themes and patterns in creating a coding schema addressing how nontraditional students perceive an inquiry-based curriculum differently than a traditional style taught curriculum (Figure 4.11).

These focus group interviews were also used as validity checks of the responses given to survey items. A main question to address here is: Do the focus group interview responses seem to line up with the survey responses? These interviews allowed me to probe for depth in the focus group setting to find out what students meant when they selected a certain answer of the Likert scale.

Three theories clearly emerged when the focus interviews were analyzed. I find it advantageous to briefly reintroduce these theories at the beginning of the discussion of this objective. This will help lay a foundation for eventually describing the presence of these theories within the focus group interview's coding schema (Figure 4.16). These three theories are conceptual change, social constructivism, and situated cognition.

Theoretical Foundations

Conceptual change theory as described in detail earlier in this dissertation, is best described by Posner et al. (1982) as the process by which individuals' conceptual frameworks change from one set of concepts to another incompatible with the first. Conceptual change involves changing old ideas with new ideas. Social constructivism is a theory of constructivism that includes the role of society and culture in cognitive construction (Peters and Stout, 2011). Brown (1989) described situated cognition theory as learning within practical activity and within the environment of real life context and culture. These three theories have helped influence this research project in that these beliefs have given more credence to the rationale for using inquiry-based instruction in my classroom. True inquiry-based teaching incorporates all three theories of how students learn.

First, frontal teaching (teacher passes knowledge to the student) has been frowned upon for many years now. Because social context is an integral part of the learning process, my aim in this research endeavor was to step back and be a “guide by the side.” My goal in my inquiry-based courses was to provide the best materials and learning situations that involved social exchanges, hoping that students would construct their own worldview in social interactions. Keeping in mind that students might replace or modify prior scientific beliefs or add to current scientific knowledge, activities were created to stimulate conceptual change. For example, in the inquiry courses I allowed students to experience failure or cognitive conflict that challenged their current conceptions. We discussed misconceptions as a class so that so that all could mentally construct more accurate conceptual frameworks.

Recognizing that learning is situated within the context of real-life investigative problem-solving, investigations were conducted within a relevant context. For example, in the inquiry course learning activities were constructed to mimic the scientific culture. Thus, collaborative learning and thinking in teams was practiced. Students had the opportunity to learn science talk and actually do the work of scientists. For example, enculturation of students into the scientific process was accomplished. Although I feel I could have created a more stimulating inquiry atmosphere in my inquiry-based classroom, students did have the opportunity to experience the process of real science; real science incorporates social constructivism, conceptual change, and situated cognition.

Major Themes

> Schools that teach for understanding engage students in doing the work of writers, scientists, mathematicians, musicians, sculptors, and critics in contexts as realistic as possible, using the criteria of performance in the disciplines as standards toward which students and teachers strive. (Darling-Hammond, 2009, p.55)

Whether or not my students ever work in a scientific field, it is my goal to train them as if they will because they will all encounter science in some way throughout their life. A wise teacher listens to his or her students and learns from them the ways they learn best. How do nontraditional, non-major biology students perceive a traditionally-based curriculum differently than an inquiry-based curriculum? Whether I was interviewing a group of students who previously learned under a more traditional style or a group of students who had just learned under the inquiry-based style, three major themes surfaced as to what students consider an effective science curriculum. These themes were connection, interaction and application. The first two themes and corresponding codes emerged in a similar way from the focus groups of both style courses. The third theme emerged in a similar way as the first two but students from the different style courses perceived effective application in various ways, resulting in some different codes (Figure 4:16). Interestingly, the first letters of the three overall themes spell C.I.A. Just as the Central Intelligence Agency gathers information to educate, serve, and protect, we also do many of the same things in our classrooms for our students.

Theme: Connection

"When you sat down and gave us real life connections to make so we could understand in a simpler form is a better way for everyone to understand it" (TCF12#19).

> I took a past course where he related things to everyday life, and I learned a lot in that class as well. That's how I retain information; if it's something I can actually use, I keep it. It's *not* just: Take a test, dump that information, move on… If I can use it, I keep it. (ICS13#4)

Providing real life connections when teaching helps students relate better to the material they are learning. A first step in addressing student misconceptions, is first providing a conceptual connection to a student's background knowledge (Wright & Bilica, 2007). If a teacher fails to connect with the background knowledge, then the student's misconceptions will never surface. If old ideas are not brought to the conceptual table, then they cannot be outcompeted by new ideas. This is a first step in conceptual change. It makes sense that students feel that they must establish a connection with course material before they feel like they are actually learning effectively. To further stimulate conceptual change, it is always advantageous to situate learning in the context and culture of real life science. This is where situated cognition comes in. Like the student above states, if the science activities are applicable to real life problems then learning becomes more concrete.

Once a connection is established and background knowledge surfaces, then conceptual frameworks need to be challenged. One way to do this, is to use today's computer technology to paint more accurate pictures of scientific phenomena.

> There was one – I think it was the one about the flu – and it had the two cells that the other cells had to go and find. I was just thinking, 'That is so cool', and I went to work the next day and I was actually trying to talk to my other service advisor about it, and she was like, 'number 4' , you're crazy. (TCF12#4)

Not only does computer animation sometimes engender excitement about the topic at hand, but it also has the potential to change inaccurate conceptual pictures to more accurate ones. The clip that this student is referring to, shows with great detail how immune cells function. It was clear that most students had not pictured cells this way. Their conceptions were changed in a matter of minutes due to today's technology. The animation in these clips is so amazing that one student stated: "The heart attack one was cringe-worthy" (TCF12#6)! Visual stimulation along with stimulation of the other senses makes for a good learning recipe. This same student stated: "Everything about those 'Body Stories' - the music, the atmosphere, was epic – you had a freaking orchestra; you had the guy who sounds like Morgan Freeman narrating." Establishing a connection through animation has tremendous potential to bring about conceptual change.

In recent years in the world of science education, there has been an emphasis on a theme-based approach to teaching science courses. However, most introductory college biology textbooks for example, still present biology in a survey format, moving up from the atom, step-by-step, to the organism. The problem with this is that most students don't grasp the big picture until the end. Because of this disconnection with the overall story or theme, rote memorization over conceptual understanding becomes a norm for many (Chaplin & Manske, 2005). This reality was clearly seen, as students talked about this problem in my own focus group interviews. One student said:

> If it was something I could relate to and work my way down [I understood it.] I used to hate science classes because they would be like 'we are going to do cell structure for two weeks.' I would be like 'NO!' (TCF13#4)

Situating learning in an environment where student can constantly connect what they are learning to a larger, relevant theme, produces deeper comprehension and ultimately, conceptual change. Darling-Hammond (2009) writes: "A compartmentalized curriculum delivered in forty two-minute class segments devoted to the coverage of large quantities of information does not easily support understanding of that information" (p.57). The benefit of using the course theme approach was appreciated by many of my students. One student said: "That's what I liked – how everything related. You related everything back to homeostasis in our body. So, that was good, how you wrapped it up in the end" (ICS13#5). Another said: "I just think the thing about homeostasis helped me put everything together. I'd never thought about that word before, but now, I get the big picture" (ICS13#8). If our conceptual world is, as Özdemir and Clark (2007) would describe it, "as a web-based relationship between concepts," then fixing one's misconceptions requires having a solid conceptual infrastructure to connect to. Immersing a course in an overall relevant theme helps expand this infrastructure.

Theme: Interaction

Students in all my focus group interviews agreed that professor-to-student and student-to-student interaction plays a vital role in how much a student learns in a course. First, a teacher's personality or demeanor can have a heavy impact on student learning. From the words of a kindergarten teacher in Wisconsin, teachers of all levels can learn a great lesson. She writes: "It's my job to find the passion, to open eyes and weave a web of intrigue and surprise." She goes on to talk about how too many teachers are simply "passion-impaired." Enthusiasm goes a long way in the classroom.

> It just goes to show that a lot of teachers, especially in college, like number two was saying, get the book and all that good stuff , but I mean, it seemed that you actually had heart for it. Like I mean you stood on the table one night. (TCF12#2)

Effective teachers often love what they do. The zeal they emanate is contagious. Someone who loves his or her discipline, and in so doing presents it in such a way as to gain his or her students attention, finds learning to be a common byproduct. Conceptual change is contingent on first capturing this attention or interest. Once students are tuned in, then it is the teacher's responsibility to provide a learning environment that challenges students' misconceptions. In this atmosphere of exposed misconceptions, one direction a teacher can go is teacher modeling. "You know like when you did the thing with the balloon and the beaker, a lot of people just don't do that. A lot of people don't show the activity" (TCF12#2). Coaching or modeling is not only an important aspect in bringing about conceptual change but it is vital in the theoretical foundation of situated cognition. Modeling how a real scientist would approach a problem in a context as real as possible is important, because decontextualized knowledge is often fragmented and incomplete (Spiro, Feltovich, Jacobson, & Coulson, 1991). Apathetic teachers rarely take the time to model or coach their students in scientific thinking. Further, these teachers seldom feel the obligation to challenge or push their students.

> Yeah. I retained a lot of information this semester. You know when you were talking about the pair and share, when we were doing the step-by-step instructions? - And, it was your steps, and it was our steps, and it was their steps, so it was really nice, because when we were finished, we could compare afterward: 'Oh, we did it this

way, and it worked,' or 'They did it that way; it worked. Okay…' and it brought more questions to mind. (ICS13#16)

"Yeah, it was looking at everybody else's stuff, saying, "Oh, wow, I never even thought of that" (ICS13#2). Not only is modeling important, but class is discussion also vital. As mentioned earlier, research on social constructivism teaches us that science learning involves discourse between all in the classroom. The creation of a scientific community provides opportunity for all to learn from one another and construct knowledge together. Timely scaffolding by the instructor is important in making sure students are not led astray by more zealous students who may have some mistaken beliefs. Students in all the courses under investigation really seemed to enjoy discussing scientific problems with one another, and appreciated a learning community rather than learning primarily from one who seemed to have all the knowledge. As this student says: "It is not just you [professor] talking all the time, we get to share" (ICS14#10). Survey results confirmed this finding. However, surveys indicated that on average those in the inquiry-based courses acquired a greater affinity toward small group discussions by the end of the courses compared to their counterparts in the traditionally-based courses. In fact, the traditionally-based courses average on this topic decreased slightly (Figure 4.12 Q9). Perhaps students enjoy small group discussions even more when it is based on discoveries made in class as opposed to discussions of other kinds. The literature does seem to support this idea and was discussed in detail under objective two.

Burrows (2003) showed that students' in a discovery-based course with discussion increased in their interest in science over the control group that was more teacher-centered with less discussion. Brownell et al. (2012) found that a cookbook lab course

with less collaboration among peers sparked less curiosity and interest then the counterparts in the inquiry lab with more collaboration. Kazempour et al. (2012) conducted a research-based course with much discussion. They found more positive attitudes toward science with these students in comparison to students in other courses. Although students enjoy freedom to explore and learn from one another in a course, they also appreciate many aspects of accountability and scaffolding provided by an organized instructor. According to these students in these focus group interviews, projects that are assigned without any guiding structure are undesirable. Although they like a certain amount of freedom, such things as deadlines were considered important to keep them on task. Several students mentioned unique helpful scaffolding measures. “With the projects, you split it up into sections and say, this half of the project is due at this stage so you can progress little by little” (TCF12#19). Another student said “I had a teacher do that too; it was like a checklist. That way, people could do it and check it off. That would probably be good too” (ICS13#12). It is clear that when it comes to longer term projects students want more checks and balances because they seem to distrust their own self-discipline. Providing certain accountability measures is quite appropriate in mimicking the scientific context and culture. In modeling how the real scientific process moves from a question all the way to publication, one must make students aware of common pitfalls. One of these pitfalls is losing track of deadlines. According to the assessing attitude toward style of science teaching surveys, most students in the different classes tended to agree that setting one’s own pace for completing projects was desirable, in fact this desire increased for most by the end of their respective courses. However, these interviews suggest that they do prefer deadlines of some sort.

Scaffolding of this sort is very important in helping students traverse complex tasks. The literature speaks to this. McKee (2007) conducted a study with collegiate individuals where he mapped the scaffolding needs for teaching intellectual skills. This study supports the investigation at hand regarding the scaffolding needs of adult students. Findings included the benefit of small-scale projects on the way to larger overall goals and deadlines much like what was desired of the students in these focus group interviews. Scaffolding plays a vital role in an inquiry-based course as shown by many studies with younger students. Meeting students where they are at and chunking the content for them, makes the learning process easier. Li and Lim (2008), in a case study of two secondary school classrooms, found scaffolding beneficial to online historical inquiry tasks. Their findings indicated that scaffolding at different steps of a project improved lower secondary students' online historical inquiry skills. The pair and share technique used in this study, was a scaffolding tool used to help students stop and think about what they were doing. This allowed students to re-orient themselves on a task before moving forward. More on scaffolding in an inquiry-based class is found in the next section when discussing how certain labs were broken up (mini-labs).

Theme: Application

> I would say science should be taught – and this is from my personal experience – is that it should be more hands-on. It should be more us exploring and experimenting and stuff because when it comes to the lecture, I take in lecture stuff, but I learn more when I'm actually doing it. That's, I guess, what type of learner I am, but I tend to think science should always be more hands-on. That's what scientists do – they're

> hands-on. I learn more that way than I would if you were constantly lecturing. (ICS13#12)

No matter which course interview transcripts I evaluated, one especially clear trend was apparent. That trend was that students want science courses to have a large application emphasis. Although the traditional course students were taught with cookbook labs following lecture presentations, many of them expressed optimism toward inquiry-based activities when asked about them. In fact, survey results confirmed their desire for more open exploration. Question number six on the assessing attitudes toward the style of science teaching, indicated an overall decrease in their desire for step-by-step directions. However, these interviews revealed that fear of frustration associated with inquiry-based labs caused most of them to declare that they would prefer cookbook labs if given the choice. It was clear that most had a feeling of anxiety with the thought of completely abandoning cookbook directions. Most were used to cookbook labs and had developed a sense of security in this form of experimentation. This was apparent with this student's comment: "Forming your own questions is good, but like you need step-by-step to kind of refer back to if you're stuck" (TCF12#19). Some students in the inquiry-based course expressed that they were indeed frustrated at times. This is not surprising, for the process of conceptual change often involves failure and mental conflict. Brickman et al. (2009) found that student frustration often stemmed from the mental effort that students were not expecting to put out. One student in my inquiry-based course said:

> I didn't like not having the step-by-step, but I do think it made me learn, made me think. Maybe because, it was the end of the day, and, I didn't want to have to think, but it made me think. (ICS13# 17)

Critical thinking in socially constructing new knowledge with their lab team and in the environment of the real scientific process generated an awareness of the mental rigor that often goes into true scientific investigation. Although frustrated at times, most students in the inquiry-based courses still preferred exploring over cookbook directions, a finding Brickman et al. (2009) also found. On average, survey results indicated an increase in their desire for more open investigation in science class (Figure 4.12, Q8 & 11). Other frustrations for students in the inquiry-based course stemmed from my own inexperience with inquiry-based ways of teaching. Gormally et al. (2011) found that an inquiry-based curriculum was not only difficult for instructors to put together but also to teach depending on their prior experience with this style of instruction. Although I faltered sometimes with this new way of teaching, most students in the inquiry courses really liked this style of pedagogy. One student said, "We felt more like scientists, because we got to have more control over the experiments, and I feel like you learn more that way" (ICS13#12). A key that I learned and many of the teachers learned in the Brickman et al. (2009) study was finding the delicate balance of scaffolding with the guided inquiry approach. This guided approach was the teaching style that nearly all students from the inquiry courses said they would enjoy and felt would be the most helpful in their future science courses. This was apparent from comments like:

> I think before the class, when I came in, I thought I wanted more guidance, but I'm glad you did it the way you did. I liked how you put the words up there. It made us think. I mean, instead of just putting the answer there, before us, it made us wonder, 'What *do* we need to do'? (ICS13#2)

“Yes guided inquiry! I just need to know a little about what I am to do so I have an idea and then I can ask questions and get explanations about what I am seeing while I do it” (ICS14#6). The following quotes sum up the guided-inquiry optimism of those in the traditional style taught group. “Less direction, but at the same time, if we need help, you know” (TCF12#6). “It’s like a balance” (TCF12#19).

Scaffolding in a guided inquiry course requires creativity at times. Simons and Ertmer (2005) conducted a study looking at scaffolding disciplined inquiry in problem-based environments at the K-12 level. Scaffolding which according to them is defined as tools, strategies, or guides that can help support learners in inquiry-based classes, can come in many forms. Regardless of the form, they should accomplish three things: “1) initiating students’ inquiry; 2) aiding learners with concept integration and addressing misconceptions; and 3) promoting reflective thinking” (p. 1). Simons and Klein (2007) showed both quantitatively and qualitatively, that students who are taught with scaffolding show greater academic achievement. These results support the below student quotations that expressed their desire for scaffolding in the form of mini-labs. I define mini-labs as a large lab exercise broken up into small experiments. As mentioned above, this way of teaching helps students re-orient themselves or become more established in foundational principles before moving onto tasks that are more complex. The majority of students in all the classes under investigation seemed to agree that their needs to be a change in the standard scheduled lecture and lab time. Long uninterrupted labs and especially long uninterrupted lectures were frowned upon by many. Most students concluded that blending the lab exercises with the lecture or discussion was the best approach. Further, having constant mini-labs seemed to be helpful to the majority of

them. Perhaps challenging students' previous conceptions by the way of many small experiments supplemented with peer and instructor deliberation is more effective than trying to bring understanding through large or long uninterrupted experiments. Simon and Ertmer (2005) work mentioned above seems to support this. Kolodner et al. (2003) recommends narrowing tasks to make them more manageable. This literature supports students' comments that alluded to the idea that a week's worth of material would be better received with several short experiments intermingled with discussion as opposed to long uninterrupted lectures or labs. Student quotes confirmed this. "Doing the experiments with the lecture helped because you get to see it after you learn about it. You get to see how it affects" (TCF13#2). "Split it up a little bit" (TCF12#19).

> I liked that we didn't just start on slide one and end on slide 80 for example and then do the lab. You went 5 slides on explaining something and then we went to the lab, and then we would set up and do a little bit and then you would explain a little bit more etc. (ICS14#5)

"I want to listen a little bit, then get the chance to explore a little bit" (ICS13#17). Knight and Wood (2005) saw positive effects in conducting their interactive inquiry-based lectures in a similar format. They did not conduct the lectures in the laboratory, so heavy equipment laden experiments were not possible, but they did intermingle the lecture with many collaborative, problem-based mini-activities. Their work showed that it is possible to supplement lectures with investigations even in lectures with large numbers of students. With the advent of computer technology and online communication, some professors at various universities are "flipping their classroom." In this form of teaching, students are required to watch more formal lectures online before they come to class. To

keep students accountable in making sure they watch the online lectures, each online lecture is followed by a required test of some sort. Scheduled lecture time is then used for more interactive, inquiry-based activities with discussion (Berrett, 2012). This seems like a reasonable approach if one wants to use class time based around social constructivism and situated cognition.

I conclude this section on application in discussing how the students in this study feel about the sequence of instruction in lab-based college courses. The majority of those from the traditionally-based course liked the way their biology course was taught. They felt more comfortable with having a detailed lecture that explains the topic at hand first before they explored the topic. Most agreed with the following students comment regarding doing lab before lecture: "I think I would be confused on what we were doing" (TCF13#18). Although I don't think most understood the guided-inquiry based approach at this point, the majority of the students felt uncomfortable diving into the unknown. A handful of students in these traditionally-based courses did see the value of exploration first. "The way we do it now, you already know what the results will be, but when you do it first, you're going to have more questions as to why it's happening. It makes you more interested in the lab" (TCF12# 24). "You would have to figure out what you did wrong and what you did right and it requires more attention" (TCF13#17). Generating questions and learning from mistakes is fertile ground for conceptual change. Most in the inquiry-based course did see the value of exploration before explanation (lab before lecture) after learning under this curriculum. In fact, most said they would prefer this in future science classes. Comments from this group included:

> I like lab first, basically because I'm the kind of person who likes to get the wheels turning. I'm a very hands-on person, so it's only natural I would like lab first. Also, when I don't know what to expect, it's more interesting to me. When I have the lab first, I don't know what to expect; and then, when the lecture follows that, I'm able to make connections. (ICS13#4)

"I think it's better to do the lab before because if you do the lecture beforehand, you sort of explain everything away, and the mystery is gone. During the lecture, you'll get to a deeper level" (ICS13#1). Question 14 of the attitudes toward style of science teaching survey seemed to indicate a contradiction between the survey response and the interview response on this topic. Inquiry-based student's preference for exploring before explaining decreased slightly over the duration the course. As mentioned under objective two, interview results explain this fear-based anomaly. Inquiry-taught students interpreted this statement as indicating no or very little pre-lab modeling or direction. When asked if they preferred exploring or lab with pre-lab scaffolding before the lecture or discussion, they embraced the concept of exploring before explaining. Contradictions were scarce between survey results and interview comments. Through analyzing the interviews and surveys as a whole, clear trends eventually immerged surrounding the contradictions that seemed to exist.

It is apparent that conducting a guided-based laboratory before lecture explanation can be very fruitful. Although scientists carry out detailed background research before investigation, much of the research is discovery based. Learning within a community, scientist's conceptions change as new discoveries are made involving real life

investigations. Inquiry-based teaching although guided, begins to help students experience the reality of thinking and acting like real scientists.

Conclusion

The main reasons for embarking on this research journey were threefold. First, it was my goal to immerse myself in the literature of science teaching. Second, I wanted to apply what I learned about inquiry-based techniques to make my science courses more exciting and interesting. Third, I wanted to find new ways to facilitate greater conceptual understanding among my students. I have certainly accomplished my first goal, but have I succeeded with my second and third goals? Results from this research project would indicate that I have been partially successful. Survey and interview data have indicated on average, that those students who went through the inquiry-based course did acquire a greater affinity toward inquiry-based learning and generated more positive attitudes toward science in general. In fact, the positive attitude change toward science for the inquiry-taught students was significantly different from that of those students taught via traditional methods. Two of the greatest differences on the attitude toward science survey dealt with statements involving interest in science. These results support similar findings in the world of collegiate science education (Brownell et al., 2012). Attitudes are important as was seen in this study. On average, inquiry course students with more positive attitudes toward science and toward inquiry teaching did do better on the content test although strong correlations were not established. Findings from this research project, as mentioned earlier, do indicate that inquiry course students did receive significant understanding of process of science or scientific practice concepts in comparison to their counterparts; however, more research is needed to confirm this

finding. Whether my students in the inquiry-based course received greater understanding of overall content in comparison to those in the traditional style course remains unanswered. They did score slightly higher from pre to post-content test, but results were not significant. Research involving the effectiveness of inquiry to engender greater overall content achievement at the higher education level still remains an open question (Neuby, 2010).

Interviews in this project were especially enlightening for me. It is very apparent that all students learn in a variety of ways, and different teaching techniques will impact students differently (Basey, Sackett, & Robinson, 2008). Interviews unveiled the diversity of the learning preferences in the students I taught. Inquiry-based course content achievement variability and the findings on the attitude toward teaching style survey further supports this point. It became very clear from the interviews that students want balance. All interviews and survey results revealed that students don't want to totally abandon the traditional lecture but want shorter, more interactive lectures that connect with them. Proponents of inquiry-based teaching do not recommend abandoning all traditional methods. Lectures can be, and often are, important, even in inquiry; where lectures occur and their purpose can be different (Marshall, 2009). Regarding inquiry, students clearly want guided inquiry over open inquiry (minimal guidance). Each professor must find their own unique combination of teaching techniques to meet the needs of their unique students. To complicate things further, this can change from semester to semester and from course to course. Inquiry-based teaching holds great promise, and from what the research has indicated so far, is worth embracing. However, "inquiry methods are not a panacea for college student learning" (Neuby, 2010, p. 4). My

anticipated hypothesis that inquiry would significantly generate a more positive attitude toward science was supported. However, anticipated hypotheses that inquiry would significantly impact overall content achievement and attitude toward inquiry teaching was rejected.

It has been over thirty years since the learning model of conceptual change was formulated. Posner et al. (1982) work exhibited that a learner must first be dissatisfied with existing ideas and that the new ideas must be seen as intelligible, plausible, and fruitful. A major goal of the investigation at hand was to design a course that would maximize this process and even reveal further insight into the theory of conceptual change. Conceptual change from course beginning to course end between the students in the two different style classes did not differ much when it came to overall content achievement. However, this study adds strength to the conceptual change concept in the area of understanding the process of science or scientific practices.

The instructional method of inquiry-based teaching is a strategy for teaching toward conceptual change. "Inquiry engages students in the exact same questioning of one's preconceptions and challenging of one's own knowledge that is characteristic of both conceptual change and scientific habits of mind" (Tanner & Allen, 2005, p. 113). Like in many areas of science, students enter the classroom with existing prescientific misconceptions. These misconceptions are often in the area of how scientists actually practice science in the research setting. The five step scientific method diagrams that are frequently displayed in textbooks, often give students wrong ideas about the process of science. The inquiry courses developed for this study followed the outline of Nussbaum and Novick (1982) in teaching toward conceptual change. They proposed that the

instructor should first make a learner's alternative frameworks plain to them. Next, it was suggested that one presents evidence that does not fit with students' conceptual ideas and so induces dissatisfaction. Finally, it was advised that a teacher present the new framework, based on real science, and explain how it differs from previous anomaly. During the first week of the inquiry courses, an incomplete concept map was presented to students regarding the process of science. In an effort to bring out misconceptions, students were asked to work through the map based on what they knew about the scientific process. After an engaging news clip that helped connect this material with students' background knowledge, an instructor-generated question was presented to them. Students formulated hypotheses and then worked in teams in coming up with an experimental procedure to test these hypotheses. They then put this procedure into practice. Dissatisfaction was often generated when discoveries were made about the scientific process that did not line up with the way they felt the scientific process proceeds. We then discussed as a class more acceptable ways that scientists usually practice science in the research setting. Discussions gave students the opportunity to build on and generate new conceptions that were more intelligible, plausible and fruitful then their previous conceptions. This inquiry-based process was common throughout the inquiry-based courses. Results from this study showed that students who learned this way experienced a significant change in conceptions regarding scientific practices from the beginning of the course to the end. Those who learned under methods that were more traditional did not experience significant change in this area.

The conceptual change theory is an important theory in the realm of science education. As seen in this study, conceptual change is vital in helping students learn

about how scientists really engage in developing and testing new knowledge. Although it is over three decades old, conceptual change theory still plays an important role in our understanding about how students learn. If the goal is to immerse students in real science in our classrooms, than we must create an atmosphere by which we can allow our students to go through the same cognitive conflict and conceptual reorganizing of ideas that real scientists go through.

The benefits of progressivism's influence on education would have never impacted classroom instruction had it not been for reflective teachers. The progressive pioneers had the desire to be life-long learners not only in their subject areas but also in the art of teaching. As these individuals continued to learn about learning, the progressive education movement surged forward. "And our schools must be the labs for learning about learning. Only if schools are run as places of reflective experimentation can we teach both children and their teachers simultaneously" (Meier, 1995, p. 202). This quote has inspired me to be in, as Meier (1995) would say, "reflective experimentation" continually. Just as I aim for conceptual change through inquiry-based practices in my biology classroom, I can continually do the same in learning about teaching. The thought that questioning, data analysis and critical thinking can permeate my career is exciting. Action research can and should go on throughout a teacher's career. "What has not changed is that teachers remain people who are intrinsically moved to be lifelong learners. Teachers are dedicated to learning and to improving their practice" (Bullough, 2009, p.76).

Future Research

> There are no valid reasons—intellectual, social, or economic—why the United States cannot transform its schools to make scientific literacy possible for all students. What is required is national commitment, determination, and a willingness to work together toward common goals. (American Association for the Advancement of Science [AAAS], 1989, p. 1)

Since the time of this document called *Science for all Americans*, the science education community has been pushing more heavily toward equitable science education for all students. First published in 1967 by Karplus and Their, learning cycle approaches of teaching which are based on three phases of instruction (exploration, concept introduction, and concept application) have been used in this push. Research at the pre-college has shown that inquiry-based teaching, which is a learning cycle model of instruction, has contributed toward the goals of excellence and equity laid out in *Science for all Americans* (American Association for the Advancement of Science [AAAS], 1989). This conviction of "science for all" should not only cover the pre-collegiate level but should extend to the higher education level as well. Future extensions of the present investigation are twofold. First, I would like to look into how inquiry-based teaching could be used to help traditionally low-performing student groups in the sciences. Specifically, I would like to look into how inquiry-based teaching in the college classroom impacts African American students. Does a science curriculum that is inquiry-based versus a science curriculum that is more traditionally-based, produce more positive academic results in African American college students? Further, with the advent of advanced computer technology and online instruction, learning science via the computer has grown exponentially. Thus secondly, I would like to investigate the effectiveness of

inquiry-based teaching in science classes that are taught online. How is inquiry-based teaching being used to meet the needs of the online student? Is a traditionally-based online science course just as effective as an inquiry-based online science course?

Although inquiry-based teaching has been shown to be very academically positive in science classrooms with majority and minority students from K-12, “at the college level the data are mixed as to whether increasing inquiry instruction can significantly change students learning or attitude toward science” (Brickman, 2009, p. 3). To help delineate this controversy, more data are needed regarding the effectiveness of inquiry on student conceptual understanding and attitude toward science. Further, little research has addressed student academic and attitude changes when entire college science courses are transformed from traditional approaches to more inquiry-based approaches. As opposed to just studying results from inquiry-based isolated activities, how will minority and online students respond to an inquiry-based course versus a traditional style course? Finally, some research has been conducted to help the academic growth of college African American and online students but the research addressing inquiry-based teaching with these types of students at the higher education level is sparse at best. This proposal lays the ground work for a future study to address the gap in the literature addressing science learning under inquiry-based techniques by minority and online students.

REFERENCES

Agresti, A., & Finlay, B. (2009). *Statistical methods for the social sciences* (4th ed.). New Jersey: Pearson Prentice Hall.

Alkhawaldeh, S. A. (2007). Facilitating conceptual change in ninth grade students' understanding of human circulatory system concepts. *Research in Science & Technological Education, 25*(3), 371-385.

Alouf, J. L., & Bentley, M. L. (2003, February). *Assessing the impact of inquiry-based science teaching in professional development activities, PK-12.* Paper presented at the annual meeting of the Association of Teacher Educators, Jacksonville, FL. Abstract retrieved from ERIC Document Reproduction Service No. (ED475577)

American Association for the Advancement of Science. (1989). Science For All Americans. Washington, DC: American Association for the Advancement of Science. Retrieved from http://www.project2061.org/publications/articles/2061/sfaasum.htm

Anderson, R. D. (2007). Inquiry as on organizing theme for science curricula. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 807-830). Mahwah, NJ: Lawrence Erlbaum Associates.

Angell, B., & Townsend, L. (2011). *Designing and conducting mixed methods studies.* Workshop for the 2011 society for social work and research annual meeting, Rutgers School of Social Works.

Assaraf, O. B., Dodick, J., & Tripto, J. (2010).High School Students' Understanding of the Human Body System. *Research in Science Education, 43*(1), 33-56. doi: 10.1007/s11165-011-9245-2

Basey, J., Sackett, L., & Robinson, N. (2008). Optimal Science Lab Design: Impacts of Various Components of Lab Design on Students' Attitudes Toward Lab. *International Journal for the Scholarship of Teaching and Learning, 2*(1), 1-15. Retrieved from http://www.colorado.edu/ebio/sackett/LorenSackett/Publications_files/PTLC_paper.pdf

Beichner, R. J., & Saul, J. M. (2003, June). *Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project.* Proceedings of the International School of Physics, Varenna, Italy. Retrieved from http://www.ncsu.edu/per/Articles/Varenna_SCALEUP_Paper.pdf

Belk, C., & Borden, J. (2007). *Biology: Science for Life* (2nd ed). New Jersey: Pearson Prentice Hall.

Bell, J. (1999). Statistics anxiety: The nontraditional student. *Education, 124*(1), 157-162.

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying Inquiry Instruction. *The Science Teacher.* Retrieved at www.nsta.org/publications/news/story.aspx?id=50983

Berg, C. R., Bergendahl, V. B., Lundberg, B. S., & Tibell, L. E. (2003). Benefiting from an open-ended experiment: A Comparison of attitudes to and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education, 25*(3), 351-372.

Berrett, D. (2012, February 3). How 'flipping' the classroom can improve the traditional lecture. *The Chronicle of Higher Education*. Retrieved from http://chronicle.com/article/How-Flipping-the-Classroom/130857/

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability? A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education, 94*(4), 577-616. doi: 10.1002/sce.20390

Board, N. S. (1996). *Science and engineering indicators.* Washington, DC: US Government Printing Office.

Bonnstetter, R. J. (1998). Inquiry: Learning from the past with an eye on the future. *Electronic Journal of Science Education, 3*(1), 1-2. Retrieved from http://ejse.southwestern.edu/article/view/7595

Bowl, M. (2001). Experiencing the barriers: nontraditional students entering higher education. *Research Papers in Education, 16*(2), 141-158.

Brickman, P., Gormally, C., Armstrong, N., & Hallar B. (2009). Effects of inquiry-based learning on students/ science literacy skills & confidence. *International Journal for the Scholarship of Teaching and Learning, 3*(2), 1-22.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Brown, P. L., Abell, S. K., Demir, A., & Schmidt, F. J. (2006). College science teachers' views of classroom inquiry. *Science Education, 90*(5), 784-802. doi: 10.1002/sce.20151

Brownell, S. E., Kloser, M. J., Fukami, T., & Shavelson, R. (2012). Undergraduate Biology Lab Courses: Comparing the Impact of Traditionally Based "Cookbook" and Authentic Research-Based Courses on Student Lab Experiences. *Journal of College Science Teaching*, *41*(4), 36-45.

Browning, M. E., & Lehman, J. D. (1988). Identification of student misconception in genetics problem solving via computer program. *Journal of Research in Science Teaching, 25*(9), 747–761. doi: 10.1002/tea.3660250905

Brumby, M. N. (1984) Misconception about the concept of natural selection by medical biology students, *Science Education, 68*(4), 493–503. doi:10.1002/sce.3730680412

Bruner, J.S. (1961). The act of discovery. *Harvard Educational Review, 31*(1), 21-32.

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research, 6*(1), 97-113. doi: 10.1177/1468794106058877

Buerck, J.P., Malmstrom, T., & Peppers, E. (2003). Learning environments and learning styles: Nontraditional student enrollment and success in an internet-based versus a lecture based computer science course. *Learning Environments Research, 6*(2), 137-155.

Bullough, R. V. (2009; 2001). "Uncertain Lives: children of Promise, Teachers of Hope," In C. Kridel (Eds.), *Classic Edition Sources: Education* (pp.74-81). New York, NY: McGraw-Hill.

Burrowes, P. A. (2003). A Student-Centered Approach to Teaching General Biology That Really Works: Lord's Constructivist Model Put to a Test. *The American Biology Teacher, 65*(7), 490-502.

Chaplin, S. B., & Manske, J. M. (2005). A theme-based approach to teaching non-majors biology: Helping students connect biology to their lives. *Journal of College Science Teaching, 35*(1), 47–51.

Chi, M.T., & Roscoe, R. D. (2002). The process and challenges of conceptual change. In M. Limon (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 3-27). Dordrecht: Kluwer.

Christianson, R. G., & Fisher, K. M. (1999). Comparison of student learning about diffusion and osmosis in constructivist and traditional classrooms. *International Journal of Science Education, (21)*6, 687-698.

Clement, J., Brown, D., Camp, C., Kudukey, J., Minstrell, J., Palmer, D., Schultz, K., Shimabukuro, J., Steinburg, M., & Veneman, V. (1987). Overcoming students' misconceptions in physics: The role of anchoring intuitions and analogical validity. In J. Novak (Eds.), *Proceedings of the Second International Seminar: Misconceptions and Educational Strategies in Science and Mathematics, Vol. 111* (pp. 84-97). Ithaca, NY: Cornell University Press.

Coffey, A., & Atkinson, P. (1996). *Making Sense of Qualitative Data*. London. Sage Publications.

Cobern, W. W. (1993). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. Tobin (Eds.), *The practice of constructivism in science education* (p. 51-69). Washington, D.C: AAAS Press.

Colburn, A. (2000). Constructivism: Science education's "grand unifying theory". *Clearing House*, *74*(1), 9-12

Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century. (2010). *BIO 2010: Transforming Undergraduate Education for Future Research Biologists.* Washington, D.C: The National Academy Press.

Cortina, J.M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology, 78*(1), 98–104.

Crandall. (1997). Old wine into new bottles: How traditional lab exercises can be converted into investigative ones. *Journal of College Science Teaching, 26*(1), 413-418.

Creswell, J., & Garrett, A. (2007). The “movement” of mixed methods research and the role of educators. *South African Journal of Education, 28*(1), 321-333.

Darling-Hammond, L. (2009; 1997). “The right to learn: A blueprint for Creating Schools that Work,” In C. Kridel (Eds.), *Classic Edition Sources: Education* (pp.54-58). New York, NY: McGraw-Hill.

Davis-Vollum, K. S., & Greengrove, C. (2010). Developing a “Gateway” course to prepare nontraditional students for success in upper-division science courses. *Journal of College Science Teaching, 40*(1), 28-33.

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

Deutch, C. E., Jurutka, P. W., & Marshall, P. A. (2008). Pedagogical issues in teaching upper-level science courses at a "'community university". *Journal of College Science Teaching, 37*(5), 23-29.

Dewey, J. (1903). Democracy in Education. *The Elementary School Teacher*, 4(4), 193-204.

DiSessa, A. A. (2002). Why conceptual ecology is a good idea. In M. Limon & L. Mason (Eds.), *"Reconsidering conceptual change: Issues in theory and practice"* (pp. 29-60). Dordrecht: Kluwer.

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education, 3*(1), 93-101.

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education, 11*(1), 481-489.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13*(1), 105–122.

Duschl, R. A., & Hamilton, R. J. (1998). Conceptual change in science and the learning of science. In B. Fraser & K. Tobin (Eds.), *International Handbook of Science Education* (pp. 1047-1065). Dordrecht, the Netherlands: Kluwer.

Eves, R. L., Davis, L. E., & Seward, W. P. (1990). Nontraditional students as a pool of potential high-quality geology and earth-science-education majors. *Journal of Geoscience Education, 38*(1), 197-199.

Feldman, A. (2002a). Existential approaches to action research. *Educational Action Research*, 10(2), 233-252.

Fisher, K. M. (1985). A misconception in biology: amino acids and translation. *Journal of Research in Science Teaching, 22*(1), 53–62. doi: 10.1002/tea.3660220105

Foley, B. J., & McPhee, C. (2008). Students' attitudes towards science in classes using hands on or textbook based curriculum. *AERA*. Retrieved from http://www.csun.edu/~bfoley/Foley%26McPhee%20AERA08.pdf

Germann, P. J. (1988). Development of the Attitude toward Science in School Assessment and its Use to Investigate the Relationship between Science Achievement and Attitude toward Science in School. *Journal of Research in Science Teaching*, *25*(8), 689-703. doi: 10.1002/tea.3660250807

Glasson, G. E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching, 26*(2), 121-131. doi: 10.1002/tea.3660260204

Glasson, G. E., & McKenzie, W. L. (1998). Investigative learning in undergraduate freshman biology laboratories: A plot project at Virginia Tech - new roles for students and teachers in an experimental design laboratory. *Journal of College Science Teaching, 27*(1), 189-193.

Glesne, C. (2011). *Becoming qualitative researchers: An introduction* (4th ed.). Boston, MA: Pearson Education, Inc.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2011). Lessons learned about implementing an inquiry-based curriculum in a college biology laboratory classroom. *Journal of College Science Teaching, 40*(3), 45-51.

Griffard, P. B., & Wandersee, J. H. (2001) The two-tier instrument on photosynthesis: what does it diagnose? *International Journal Science Education, 23*(10), 1039–1052.

Hake, R. R. (1998). Interactive engagement vs. traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74.

Hakkarainen, O., & Ahtee, M. (2006). The durability of conceptual change in learning the concept of weight in the case of a pulley in balance. *International Journal of Science and Mathematics Education, 5*(3), 461-482.

Hall, D. A., & McCurdy, D. W. (1990). A comparison of a biological science curriculum study (BSCS) laboratory and a traditional laboratory on student achievement at two private liberal arts colleges. *Journal of Research in Science Teaching, 27*(1), 625-636.

Hammond, J. W., & Bradshaw, W. S. (2004). Inquiry in the large-enrollment science classroom. *Journal of College Science Teaching, 34*(1), 44-48.

Hampton, R.E. (1994). *Introductory biological statistics*. Dubuque, Iowa: Wm. C. Brown Publishers.

Harker, A. R. (1999). Full application of the scientific method in an undergraduate teaching laboratory: A reality-based approach to experiential student-directed instruction. *Journal of College Science Teaching, 29*(1), 97-100.

Haury, D. L. (1993). Teaching Science through Inquiry. ERIC/CSMEE Digest. Retrieved from ERIC database. (ED359048)

Hemmings, A. (2006). Great Ethical Divides: Bridging the Gap Between Institutional Review Boards and Researchers. *Educational Researcher, 35*(4), 12-18.

Herron, M. (1971). The nature of scientific inquiry. *School Review, 79*(2), 171-212.

Hewson, M. G., & Hewson, P.W. (2003). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 40*(3), S86-S98.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.

House, J. D. (1996). Student expectancies and academic self-concept as predictors of student achievement. *Journal of Psychology, 130*(1), 679-681.

Houser, M. (2005). Are we violating their expectations? Instructors communication expectations of traditional and nontraditional students. *Communication Quarterly, 53*(2), 213-228.

Hoyt, J. (1999). Remedial educational and student attrition. *Community College Review, 27*(2), 51-73.

Hughes, R. (1983). The non-traditional student in higher education: A synthesis of the literature. *NASPA Journal*, *20*(3), 51-64.

Hung, C., & Lin, C. (2009). *The nature of students' explanations about homeostasis.* Unpublished manuscript, Department of Science, National Taiwan Normal University, Taiwan.

Ingram, E., Lehman, E., Love, A.C., & Polacek, K.M. (2004). Fostering inquiry in nonlaboratory settings. *Journal of College Science Teaching, 34*(1), 39-43.

Ivarsson, J., Schoultz , J., Säljö, R. (2002). Map reading versus mind reading: Revisiting children's understanding of the shape of the earth. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice*. (pp.77-99). Springer: Netherlands.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112–133.

Kang, S., Scharmann, L. C., & Noh, T. (2004). Reexamining the Role of Cognitive Conflict in Science Concept Learning. *Research in Science Education, 34*(1), 71–96.

Karplus, R., & H. D. Thier. (1967). *A new look at elementary school science.* Chicago: Rand McNally.

Kazempour, M., Amirshokoohi, A., & Harwood, W. (2012). Exploring Students' Perceptions of Science and Inquiry in a Reform- Based Undergraduate Biology Course. *Journal of College Science Teaching, 42*(2), 38-43.

Kemmis, S. (2009). Action research as a practice-based practice. *Educational Action Research*, 17(3), 463-474.

Keys, C.W., & Bryan, L.A. (2000). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*(6), 631-645. doi: 10.1002/tea.1023

Kim, K. A., Sax, L. J., Lee, J. J., & Hagedorn, L. S. (2010). Redefining nontraditional students: Exploring the self-perceptions of community college students. *Community College Journal of Research and Practice*, *34*(5), 402-422.

Kimbrough, D. R., & Weaver, G. C. (1999). Improving the background knowledge of nontraditional students. *Innovative Higher Education, 29*(3), 197-219.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist*, *41*(2), 75-86.

Knapp, T. R. (1990). Treating ordinal scales as interval scales: An attempt to resolve the controversy. *Nursing Research, 39*(1), 121-123.

Knight, J., & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4*(4), 298-310.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design into practice. *The Journal of the Learning Sciences, 12*(1), 495-547.

Kyle, W. C. Jr., Bonnstetter, R. J., & Gadsden, T. Jr., (1988). An implementation study: an analysis of elementary students' and teachers' attitudes toward science in process-approach vs. traditional science classes. *Journal of Research in Science Teaching, 25*(1), 103-120.

Lakshmi, G. (2000). *Attitude Toward Science*. Daryaganj, India: Discovery Publishing House.

Lane, K. (2004). Sen. Clinton unveils plan to help nontraditional students. [Washington Update]. *Black Issues in Higher Education, 21*(2), 6-6.

Laws, P., Sokoloff, D., & Thornton, R. (1999). Promoting Active Learning Using the Results of Physics Education Research. *UniServe Science News, 13*. Retrieved from http://science.uniserve.edu.au/newsletter/vol13/sokoloff.html

Leonard, W. H. (1983). An experimental study of a BSCS-style laboratory approach for university general biology. *Journal of Research in Science Teaching, 20*(1), 807–813.

Lee, G., Kwon, J., Park, S.S., Kim, J. W., Kwon, H. G., & Park, H. K. (2003). Development of an instrument for measuring cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Journal of Research in Science Teaching, 40*(1), 585-603.

Li, D. D., & Lim, C. P. (2008). Scaffolding online historical inquiry tasks: A case study of two secondary school classrooms. *Computers & Education*, 50(1), 1394–1410.

Liberal Education and America's Promise (LEAP). (2011). *College learning/abr the new global generation (executive summary).*Washington, DC**:** Association of America Colleges and Universities. Retrieved from http://www.aacu.org/sites/default/files/files/LEAP/leap_vision_summary.pdf

Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*(1), 357-380.

Lindberg, D. H. (1990). What goes 'round comes 'round doing science. *Childhood Education, 67*(2), 79-81.

Lloyd, C. V., & Contreras, N. J. (1985, December). The role of experiences in learning science vocabulary. Paper presented at the Annual Meeting of the National Reading Conference, San Diego, CA. (ERIC Document Reproduction Services No. ED 281189)

Löfgren, K. (2013, May 19). Qualitative Analysis of Interview Data [Video file]. Retrieved from https://www.youtube.com/watch?v=DRL4PF2u9XA

Longbottom, J., & Butler, P. (1999). Why teach science? Setting rational goals for science education. *Science Education*, *83*(1), 473-492.

Luckie, D. B., Maleszewski, J. J., Loznak, S. D., & Krha, M. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: A four-year study of "teams and streams". *Advances in Physiology Education, 28*(4), 199-209. doi: 10.1152/advan.00086.2010

Lunsford, B. E., & Herzog, M. R. (1997). Acive learning in anatomy & physiology: Student reactions & outcomes in a nontraditional A&P course. *The American Biology Teacher, 59*(2), 80-85.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Dordrecht, Netherlands: Kluwer Academic.

Magnussen, L., Ishida, D., & Itano, J. (2000). The Impact of the Use of Inquiry-Based Learning as a Teaching Methodology on the Development of Critical Thinking. *Journal of Nursing Education, 39*(8), 360-364.

Mann, M., & Treagust, D.F. (1998). A pencil and paper instrument to diagnose students' conceptions of breathing, gas exchange and respiration. *Australian Science Teachers Journal, 44*(2), 1-11.

Manner, J. (2003). Serving the nontraditional student through a technology enhanced curriculum. *TechTrends, 47*(5), 32-35.

Marbach-Ad, G., Briken, V., El-Sayed, N. M., Frauwirth, K., Fredericksen, B., Hutcheson, S., Gao, L.Y., Joseph, S. W., Lee, V., McIver, K.S., Mosser, D., Quimby, B. B., Shields, P., Song, W., Stein, D. C., Yuan, R. T., & Smith, A. C. (2009). Assessing student understanding of host pathogen interactions using a concept inventory. *Journal of Microbiology Education,* 10(1), 43-50.

Marshall, J. C., Horton, B., Smart, J., & Llewellyn, D. (2009). *EQUIP: Electronic Quality of Inquiry Protocol*: Retrieved from Clemson University's Inquiry in Motion Institute, www.clemson.edu/iim.

Marshall, J. C., Horton, B., & White, C. (2009). EQUIPping teachers: A protocol to guide and improve inquiry-based instruction. *The Science Teacher*, *76*(4), 46-53.

Marshall, J. C. (2009, April). *The Creation, Validation, and Reliability Associated with the EQUIP (Electronic Quality of Inquiry Protocol): A Measure of Inquiry-Based Instruction.* Research paper presented at National Association of Researchers of Science Teaching (NARST) conference. Orange County, CA. Retrieved from http://iim-web.clemson.edu/wp-content/uploads/2009/04/narst-2009-equip-proceedings-paper.pdf

Marshall, J. C., Smart, J., Lotter, C., & Sirbu, C. (2011). Comparative Analysis of Two Inquiry Observational Protocols: Striving to Better Understand the Quality of Teacher-Facilitated Inquiry-Based Instruction. *School Science and Mathematics, 111*(6), 306-315. doi: 10.1111/j.1949-8594.2011.00091.x

McKee, A. (2007). Reality Versus Authenticity: Mapping the Scaffolding Needs for Teaching Intellectual Skills for Working in Television. *Journal of Learning Design, 2*(2), 43-55. Retrieved from http://www.academia.edu/4303550/Reality_versus_authenticity_mapping_the_scaffolding_requirements_for_teaching_intellectual_skills_for_working_in_televisio

McNergney, R. F., & McNergney, J.M. (2009) *Education: The practice and profession of teaching.* New Jersey: Pearson Education, Inc.

Metzner, B. S., & Bean, J. P. (1987). The estimation of a conceptual model of nontraditional undergraduate student attrition. *Research in Higher Education, 27*(1), 15-38.

Michael, J. A., Wenderoth, M. P., Modell, H. I., Cliff, W., Horwitz, B., McHale, P., Richardson, D., Silverthorn, D., Williams, S., & Whitescarver, S. (2002). Undergraduates' understanding of cardiovascular phenomena. *Adv Physiol Educ, 26*(2), 72–84. doi: 10.1152/advan.00002.2002

Meier, D. (2009; 1995). "The Power of Their Ideas: Lessons for America from a Small School in Harlem," In C. Kridel (Eds.), *Classic Edition Sources: Education* (pp.204-210). New York, NY: McGraw-Hill.

Mikkila-Erdmann, M. (2002). *Science learning through text: The effect of text design and text comprehension skills on conceptual change.* Dordrecht: Kluwer.

Millar, R. (1989). Constructive criticisms. *International Journal of Science Education, 11*(1), 587-596.

Moore, D. S. (2010). *The Basic Practice of Statistics* (5th ed). New York: W.H. Freeman and Company.

Mortimer, E. (1995). Conceptual change or conceptual profile change? *Science and Education, 4*(1), 267-285.

Morrell, P. D., & Lederman, N. G. (1998). Students' Attitudes Toward School and Classroom Science: Are They Independent Phenomena? *School Science and Mathematics, 98*(2), 76-83.

National Research Council (NRC). (1996). *National science education standards.* Washington, DC: National Academy Press. Retrieved from The National Academies Press Online via: http://www.nap.edu/

National Research Council (NRC). (1999). *How people learn: Brain, mind, experience and school.* Washington, DC: National Academic Press. Retrieved from The National Academies Press Online via: http://www.nap.edu/

National Research Council (NRC). (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academy Press. Retrieved from The National Academies Press Online via: http://www.nap.edu/

National Research Council (NRC). (2001). *Classroom Assessment and the National Science Education Standards*. Washington, DC: National Academy Press. Retrieved from The National Academies Press Online via: http://www.nap.edu/

National Research Council (NRC). (2012). *A Framework for K-12 Science Education Practices, Crosscutting Concepts and Core Ideas*. Washington, DC: National Academies Press. Retrieved from The National Academies Press Online via: http://www.nap.edu/

National Science Foundation (NSF). (1996). *Higher Education in Science and Engineering: Science and Engineering Indicators*. Washington, DC: U.S. Government Printing Office. Retrieved from http://www.nsf.gov/statistics/seind96/chap_2.pdf

Newman, W. J., Abell, P. D., Hubbard, P. D., McDonald, J., Otaala, J., & Martini, M. (2004). Dilemmas of Teaching Inquiry in Elementary Science Methods. *Journal of Science Teacher Education, 15*(4), 257-279. doi:10.1023/B:JSTE.0000048330.07586.d6

Niaz, M., Aguilera, D., Maza, A., & Liendo, G. (2002). Arguments, contradictions, resistances, and conceptual change in students' understanding of atomic structure. *Science Education, 86*(1), 505-525.

Norris, S., Phillips, L. M. & Korpan, C. (2003). University students' interpretation of media reports of science and its relationship to background knowledge, interest, and reading difficulty. *Public Understanding of Science, 12*(1), 1-23. doi: 10.1177/09636625030122001

Novak, A. (1964). “Scientific Inquiry.” *Bioscience, 14*(1), 25-28.

Nueby, B. (2010). Inquiry Teaching in the College Classroom. *The Journal of Effective Teaching, 10*(1), 4-21.

Nunnally, J. C. (1978). *Psychometric Theory,* (2nd ed). New York: McGraw-Hill.

Nussbaum, J., & Novick, S. (1982). Altrnative frameworks, conceptual conflict and accommodaton: Toward a principled teaching strategy. *Instructional Science,11*(1), 183-200.

Odom A. L., & Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students’ understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching, 32(1)*, 45–61. doi: 10.1002/tea.3660320106

Ozdemir, G., & Clark, D. B. (2007). An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science, and Technology Education, 3*(4), 351-361.

Ozkan, O., Tekkaya, C., & Geban, O. (2004). Facilitating conceptual change in students’ understanding of ecological concepts. *Journal of Science Education and Technology, 13*(1), 95–105. doi: 1059-0145/04/0400-0095/0

Paulsen, M. B. (1990). College choice: *Understanding student enrollment behavior. kSHE-ERIC Higher Education Report No. 6*. Washington, D.C.: The George Washington University, School of Education and Human Development. Retrieved from http://files.eric.ed.gov/fulltext/ED333855.pdf

Peters, J. M., & Stout, D. L. (2011). *Science in Elementary Education: Methods, Concepts, and Inquiries* (11th ed.). Boston: Pearson.

Piaget, J. (1952). *The origins of intelligence in children.* New York: International University Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education, 66*(2), 211-227.

Price, M. J., Vigeant, M. A., & Nottis, K. (2009). A preliminary study on the effectiveness of inquiry-based activities for addressing misconceptions of undergraduate engineering students. *Educ for Chemical Engineers, 4*(1), 29-41.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics, 65*(1), 45-54.

Reeve, S., Hammond, J. W., & Bradshaw, W. S. (2004). Inquiry in the large-enrollment science classroom. *Journal of College Science Teaching, 34*(1), 44-48.

Rezba, R. J., Auldridge, T., & Rhea, L. (1999). Teaching & learning the basic science skills. Retrieved at http://www.nsta.org/publications/news/story.aspx?id=50983

Rissing, S. W., & Cogan, J. G. (2009). Can an inquiry approach improve college student learning in a teaching laboratory? *CBE Life Science Education, 8*(1), 55-61.

Roehrig, G. H., & Luft, J. A. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education, 26*(1), 3-24.

Roth, K. J. (1996). Science education: It's not enough to 'Do' or 'Relate'. In M. Pearsall (Eds.), *Scope, sequence, and coordination of secondary school science* (pp.151-164). Washington, DC: National Science Teachers Association.

Rutherford, F. J. (1964). The role of inquiry in science teaching. *Journal of Research in Science Teaching, 2*(1), 80-84.

Schoultz, J., & Saljo, R. (2002). Map reading versus mind reading: Revisiting children's understanding of the shape of the earth. In M. Limon (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 77-99). Dordrecht: Kluwer.

Schwab, J. (1962). *The teaching of science as inquiry.* Cambridge, MA: Harvard University Press.

Scott, P., Asoko, H., & Driver, R. (1992). Teaching for conceptual change: a review of strategies. In R. Duit, F. Goldberg, & H. Niedderer (eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp.310-329). Kiel, Germany: University of Kiel.

Scott, P., Asoko, H., & Leach, J. (2007). Student conceptions and conceptual learning in science. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 31-56). Mahwah, NJ: Lawrence Erlbaum Associates.

Seymour, E. & Hewitt, N. M. (1994). *Talking about leaving: Why undergraduates leave the sciences.* Boulder, CO: Westview Press.

Shymansky, J. A. (1984). BSCS programs: just how effective were they? *The American Biology Teacher, 46*(1), 54-57.

Shymansky, J. A., Hedges L. V., & Woodworth, G. (1990). A reassessment of the effects of inquiry-based science curricula of the 60's. *Journal of Research in Science Teaching, 27*(2), 127-44.

Sian Davies-Vollum, K., & Greengrove, C. (2010). Developing a "gateway" course to prepare nontraditional students for success in upper-division science courses. *Journal of College Science Teaching, 40*(1), 28-33.

Simons, K. D., & Ertmer, P. A. (2005). Scaffolding Disciplined Inquiry in Problem-Based Environments. Unpublished manuscript, Purdue University, Lafayette, Indiana. Retrieved from http://www.edci.purdue.edu/ertmer/docs/simons_lc05.pdf

Simons, K. D., & Klein, J. D. (2007). The Impact of Scaffolding and Student Achievement Levels in a Problem-based Learning Environment. *Instructional Science, 35*(1), 41–72.

Song-Ling, M. & Chun-Yen, C. (1998). Impacts of an Inquiry Teaching Method on Earth Science Students' Learning Outcomes and Attitudes at the Secondary School Level. *Proc. Natl. Sci. Counc. ROC(D), 8*(3), 93-101.

Spencer, T. L., & Walker, T. M. (2012). Creating a Love for Science for Elementary Students through Inquiry-based Learning. *Journal of Virginia Science Education, 4*(2), 18-25.

Spiro, R. J. Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1991b). Knowledge representation, content specification, and the development of skill in situation-specific knowledge assembly: Some constructivist issues as they relate to Cognitive Flexibility theory and hypertext. *Educational Technology, 31*(9), 22-25.

Staver, J. R. (1986). *The constructivist epistemology of Jean Piaget: Its philosophical roots and relevance to science teaching and learning.* Paper presented at the United States-Japan Seminar on Science Education, Honolulu, HI. (ERIC Document Reproduction services No. ED 278563) Retrieved from ERIC Database at http://files.eric.ed.gov/fulltext/ED278563.pdf

Stavy, R., & Berkovits, B. (1980). Cognitive conflict as a basis for teaching quantitative aspects of the concept of temperature. *Science Education, 64*(1), 679-692.

Strage, A. (2008). Traditional and nontraditional college students' descriptions of the "ideal" professor and the "ideal" course and perceived strengths and limitations. *College Student Journal*, *42*(1), 225-230. doi: 01463934

Stukus, P., & Lennox, J. E. (1995). Use of an investigative semester-length laboratory project in an introductory microbiology course: Acquainting students with the research process and the scientific frame of mind. *Journal of College Science Teaching*, *25*(1), 135-139.

Sunal, D. W., Wright, E. L., & Day, J. B. (2004). *Reform in undergraduate science teaching for the 21st century.* Greenwich, CT: Information Age Publishing.

Sundberg, L. (1997). *Marketing analysis for the nontraditional student at Carl Sandburg College*. (ERIC Document Reproduction services No. ED 413032) Retrieved from ERIC database at http://files.eric.ed.gov/fulltext/ED413032.pdf

Sundberg, M. D., Armstrong, J. E., & Wischusen, E. W. (2005). Reappraisal of the status of introductory biology laboratory education in U.S. colleges and universities. *The American Biology Teacher, 67*(9), 525-529.

Suping, S. M. (2003). Conceptual Change among Students in Science. ERIC Digest. Retrieved from ERIC database. (ED482723)

Tanner, K., & Allen, D. (2005). Approaches to biology teaching and learning: Understanding the wrong answers - teaching toward conceptual change. *Cell Biology Education*, *4*(2), 112-117. doi: 10.1187/cbe.05-02-0068

Teixeira, F. (2000) What happens to the food we eat? Children’s conception of the structure and function of the digestive system. *International Journal of Science Education*, *22*(5), 507–520. doi: 10.1080/095006900289750

Tekkaya, C. (2002). Misconceptions as barrier to understanding biology. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, *23*(1), 259-266.

The Discovery Channel. (2001). *Body Story*. London: Wall to Wall Publishers. Retrieved from https://www.youtube.com/results?search_query=body+story+episode+

Their, H. (2000). *Developing inquiry-based science materials: A guide for educators.* New York, NY: Teachers College Press, Columbia University.

Tichenor, L. (1997). Student-designed physiology laboratories: Creative instructional alternatives at a resource-poor New England university. *Journal of College Science Teaching*, *26*(1), 175-181.

Tolman, D. A. (1999). A science-in-the-making course for nonscience majors. *Journal of College Science Teaching, 29*(1), 41-46.

Tsai, C. C., & Chang, C.Y. (2005). Last effects of instruction guided by the conflict map: Experimental study of learning about the causes of the seasons. *Journal of Research in Science Teaching, 42*(1), 1089-1111. doi: 10.1002/tea.20089

Turner, L. (2006). "Culturally competent mentoring" serves nontraditionals. *Women in Higher Education, 15*(11), 1-2.

Udovic, D., Morris, D., Dickman, A., Postlethwait, J., & Wetherwax, P. (2002). Workshop biology: Demonstrating the effectiveness of active learning in an introductory biology course. *Bioscience, 52*(3), 272-281.

U.S. Department of Education, National Center for Education Statistics. (2003). *Digest of Education Statistics, 2002, (NCES 2003–060)*. Washington, DC: U.S. Government Printing Office. Retrieved from http://nces.ed.gov/pubs2003/2003060.pdf

Vosniadou, S. (2002). On the nature of naive physics. In M. Limon (eds.), *Reconsidering conceptual change: Issues in theory and Practice* (pp. 61-76). Dordrecht: Kluwer.

Wagenschein, M. (1999; 1957). The law of free fall as an 'eemplary theme' for the mathematicizability of certain natural processes. In I. Westbury et al., (eds.). *Teaching as a Reflective Process*: *a condensed version of "Teaching to Understand: On the Concept of the Exemplary in Teaching"* (pp. 285-93). Mahwah, NJ: Lawrence Erlbaum Associates.

Wallace, C. S., Tsoi, M. Y., Calkin, J., & Darley, M. (2003). Learning from inquiry-based laboratories in nonmajor biology: An interpretive study of the relationships among inquiry. *Journal of Research in Science Teaching*, *40*(10), 986-1024. doi: 10.1002/tea.10127

Weiss, C., & Sosulski, K. (2003). *Quantitative Methods in Social Sciences e-Lessons: Measurement Validity and Reliability*. Retrieved from http://ccnmtl.columbia.edu/projects/qmss/measurement/validity_and_reliability.html

Weld, J. D., Rogers, C. M., & Heard, S. B. (1999). Semester-length field investigations in undergraduate animal behavior and ecology courses: Making the laboratory experience the linchpin of science education. *Journal of College Science Teaching*, *28*(1), 340-344.

Westbrook, S. L., & Marek, E. A. (1992). A cross–age study of student understanding of the concept of Homeostasis. *Journal of Research in Science Teaching*, 29, 51–61. doi: 10.1002/tea.3660290106

Windolf, P. (1992). Cycles of expansion in higher education: An international comparison. *Higher Education*, *23*(1), 3-19.

Wiser, M., & Amin, T. G. (2002). *Computer-based interactions for conceptual change in science.* Dordrecht: Kluwer.

Wright, A. W., & Bilica, K. (2007). Instructional tools to probe biology students' prior understanding. *American Biology Teacher*, *69*(1), 1-5.

Wyatt, L. (2011). Nontraditional student engagement: Increasing adult student success and retention. *The Journal of Continuing Higher Education*, *59*(1), 10-20. doi: 10.1080/07377363.2011.544977

APPENDIX A – TWO-TIER DIAGNOSTIC TEST

Two-tier diagnostic test measuring college biology students' understanding of major concepts related to homeostasis of the human body after a course of instruction. (some questions were created while others were modified from various diagnostic tests & crafted to fit a multiple choice format)

Choose the best answer possible!

1.Which of the following should **NOT** be part of the construction of a scientific explanation:

a. a repeatable means of data collection
b. a review of the literature to see what is previously known about the topic
c. what a scientist hopes the explanation turns out to be
d. logic/reason

2. The reason for my answer is because:

a. Scientists try to analyze data without being informed by what other scientists know
b. One set of data are enough to prove or disprove an explanation
c. Science does not require logic or reason in the construction of an explanation
d. Scientists strive to be objective, so their personal views are put aside as much as possible

The above question (1-2) were modified from Blanchard et al. (2010).
No reliability or validity data reported.

3. In a scientific experiment, hypotheses are either rejected or supported (not proven).

a. This statement is true
b. This statement is false

4. The reason for my answer is because:

a. Correlation does not equal causation
b. Scientific laws are created because of proven hypothesis.
c. Other factors (lurking variables) could affect outcomes
d. If an experiment is repeated enough with the same outcome then a hypothesis can be declared as proven or true

5. In a controlled experiment to test the effects of cocaine on *Daphnia* heart rate. The independent variable is:

a. Heart rate per minute
b. Cocaine
6. The reason for my answer is because:

a. Rate of heartbeats would go on the x axis on a graphical representation
b. Rate of heartbeats is dependent on what kind of drug it is subjected to
c. The effect of cocaine is dependent on the rate of heartbeats per minute
d. It does not matter which is the independent variable and which is the dependent variable

7. In biological systems, enzymes are:

a.Common
b.Uncommon

8. The reason for my answer is because:

a. One enzyme can be a catalyst for many reactions
b. Enzymes are altered or depleted in the course of a chemical reaction
c. Almost all chemical reactions in a cell need enzymes in order to occur at rates sufficient for life
d. Like cells that make up the body, enzymes are living entities
e. Genes carry the recipes for proteins and can only make proteins

9. Alterations in the pH of an enzyme reaction:

a. Will not affect it structure and function
b. May affect its structure and function

10. The reason for my answer is because:

a. Enzymes are proteins that are resistant to structural change regardless of its pH environment
b. Enzymes are proteins that are susceptible to structural change when not at optimal pH
c. Enzymes are carbohydrates that are fixed and cannot be broken down
d. All enzymes function at their optimal pH of 7 in the human body

11. At extremely high temperatures (i.e., near the boiling point of water) most enzymes would be predicted to:

a. Function well
b. Function minimally if at all

12. The reason for my answer is because:

a. Enzymes function only a few degrees above and below 37 degrees Celsius (human body temperature)
b. The higher the temperature the faster the rate of reaction for enzymes
c. Enzyme structure makes them resistant to extreme temperature changes
d. Enzyme structure is sensitive to extremely high temperatures

The above questions (7-12) were modified from Rissing, S. W. & Cogan, J. G. (2009). No reliability or validity data reported.

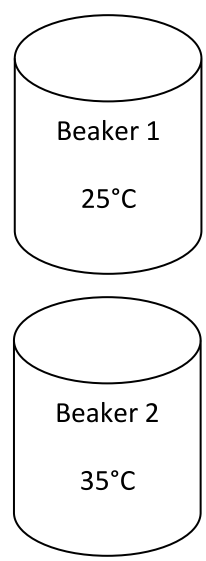
13. During the process of diffusion, particles will generally move from:
a. high to low concentrations
b. low to high concentrations

14. The reason for my answer is because:
a. there are too many particles crowded into one area, therefore they move to an area with more room
b. particles in areas of greater concentration are more likely to bounce toward areas of lower concentration
c. the particles tend to move until the two areas are balanced and then the particles stop moving
d. there is a greater chance of the particles repelling each other

15. Suppose there are two large beakers with equal amounts of clear water at two different temperatures. Next, a drop of green dye is added to each beaker of water. Eventually the water turns light green (see Figure 1). Which beaker became light green first?

a. Beaker 1
b. Beaker 2

Figure 1



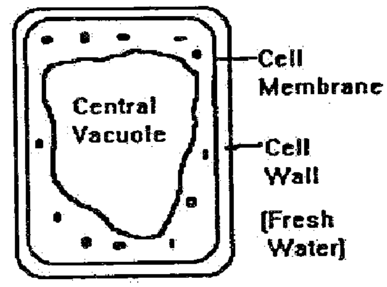
16. The reason for my answer is because:

a. the lower temperature breaks down the dye
b. warm temperature helps the molecules to expand
c. the cold temperature speeds up the molecules
d. the dye molecules move faster at higher temperatures

17. Figure 3 is a picture of a plant cell that lives in fresh water. If this cell was placed in a beaker of 25% salt water solution, the central vacuole would: Figure 3 (See Below)

a. increase in size
b. decrease in size
c. remain the same size

Figure 3



18. The reason for my answer is because:
a. Salt absorbs the water from the central vacuole
b. the salt will enter the vacuole
c. water will move from the vacuole to the salt water solution
d. salt solution outside the cell cannot affect the vacuole inside

The above questions (13-18) were modified from Odom A. L. & Barrow, L. H. (1995). Whole test reliability was estimated to be .74 using the Spearman-Brown Formula.

19. Most types of bacteria cause disease.

a. This statement is true
b. This statement is false

20. The reason for my answer is because:

a. Bacteria produce toxins — powerful chemicals that damage cells and make you ill
b. Most bacteria that live in our body and live in our environment are beneficial to us and the environment
c. Bacteria have the ability to evade our immune system and disrupt our body's internal balance
d. Bacteria are non-cellular and can't reproduce unless inside another host cell

21. Antibiotics are effective drugs in treating viral infections.

a. This statement is true
b. This statement is false

22. The reason for my answer is because:

a. Antibiotics only target aspects of microorganisms that are cellular (made up of a cell or cells)
b. Antibiotics work to damage the DNA of microorganisms
c. Antibiotics have proven to be effective in treating the common cold for many years now
d. Antibiotics target the cell wall of microorganisms

23. Two roommates fall ill: one has an ear infection and one has pneumonia. Is it possible that the same causative agent is responsible for both types of disease?
a. Yes
b. No

24. The reason for my answer is because:
a. yes, because both individuals live in the same room and therefore the source of the infection has to be the same
b. no, because one infection is in the lung while the other is in the ear
c. no, because each bacterium would cause one specific disease
d. yes, because the same bacteria can adapt to different surroundings

The above questions (23-24) were modified from Marbach-Ad et al. (2009).
No reliability or validity data reported.

25. Using DNA evidence to convict a suspected murderer requires obtaining a DNA fingerprint (DNA profile).

a. This statement is true
b. This statement is false

26. The reason for my answer is because:

a. Everyone (except identical twins) has a different number of tandem repeats (repeated DNA sequence codes) at different locations in their genetic make-up
b. Considering that different cells have different DNA, what is required is to extract the DNA from the unique cells found at the crime scene and compare it to the DNA of the same unique cells of the suspect
c. Every person's DNA is structurally different, so what is required is to compare the structural differences between the crime scene DNA and the DNA of the suspects
d. Advanced biotechnology is required to compare human's 25 -30,000 genes found in the cells at the crime scene to the 25-30,000 genes in the cells of the suspect

27. A student who could taste a bitter harmless chemical called PTC (dominant trait) decided to test his parents to see if they could also taste this chemical. It was discovered by the student that neither of his parents could taste PTC! Assuming that the parents have no non-genetic reason to be a non-taster:

a. The student still might be genetically related to his parents
b. The student is not genetically related to his parents

28. The reason for my answer is because:

a. The dominant PTC trait could have skipped a generation showing up in the student's genetics
b. The combination of the parent's genes working together in the student's body allowed him to be a taster of PTC
c. The parent's genetics has changed over time making them non-tasters, although they still share most of their son's genetics
d. The student has at least one dominant allele (gene version) which he could not have gotten from his parents
e. The alleles (gene versions) come in many forms and varieties

29. An increase in the amount of carbon dioxide in the blood causes us to breathe faster.

a. This statement is true
b. This statement is false

30. The reason for my answer is because:

a. The need for oxygen drives the urge to breathe. When oxygen is low this is detected and so we breathe faster or deeper or both. The lower the oxygen the faster we breathe.
b. Carbon dioxide concentration in the blood is detected by the brain and this stimulates us to breathe deeper and faster
c. We only detect requirements that we need. When the oxygen required is low we need to increase it. So when we detect low oxygen we breathe faster to get more oxygen.
d. Since we need oxygen, an increase in carbon dioxide indicates a decrease in the amount of oxygen and so we breathe deeper and faster to get more oxygen into our body.

The above questions (29-30) were modified from Mann, M. & Treagust, D. F. (1998). No reliability or validity data reported.

31. If all of the nerves innervating the heart are cut, the heart will:

a. stop beating immediately
b. continue beating for a short while at the same rate
c. continue beating for a short while, but at a different rate

32. The reason for my answer is because:

a. The heart has its own pacemaker that regulates its own beat
b. The heart needs impulses from nerves to beat
c. The heart has its own independent firing device that keeps it beating. The nerves going to it regulate the rate.
d. Cells beat independent of stimulus
e. Heart is a muscle and muscle contractions are nerve regulated

The above question (31-32) were modified from Michael J. A. et al. (2002). No reliability or validity data reported.

33. If you were a doctor and you collected urine from a patient, the following would not be considered normal to find in the urine of a healthy person.
a. Urea
b. H2O
c. Salts
d. Glucose

34. The reason for my answer is because:
a. Tubular reabsorption actively moves all glucose molecules back into the blood to be stored or to be used in the body to make ATP
b. Small molecules such as urea that accidently slip through the nephron filter need to be actively secreted back into the blood in the final step of urine formation
c. Water is essential for life and 70% of cells are water. Because of this all water needs to be reabsorbed back into the blood to be used in the body
d. Salt is essential for fluid balance, nerve conduction, and muscle contraction and therefore all salt must stay in the blood and be used in the body

35. Figure 4 on the following page shows the pulmonary and systemic circuit of blood flowing through the cardiovascular system. What would be the state of glucose levels in the blood in the hepatic vein of a person who ate a short time ago.

a. High glucose level in hepatic vein
b. Moderate glucose level in hepatic vein
c. Low glucose level in hepatic vein

36. The reason for my answer is because:
a. The liver release glucose into the blood in response to insulin
b. The hepatic portal vein follows the digestive tract where glucose is absorbed into the blood
c. By the time the blood reaches the hepatic portal vein, half of the glucose has been used by the cells with oxygen to make cell energy
d. The liver takes up extra glucose and stores it as glycogen
e. The hepatic portal vein is a fair distance from the digestive tract and glucose has been mostly used up when blood arrives there

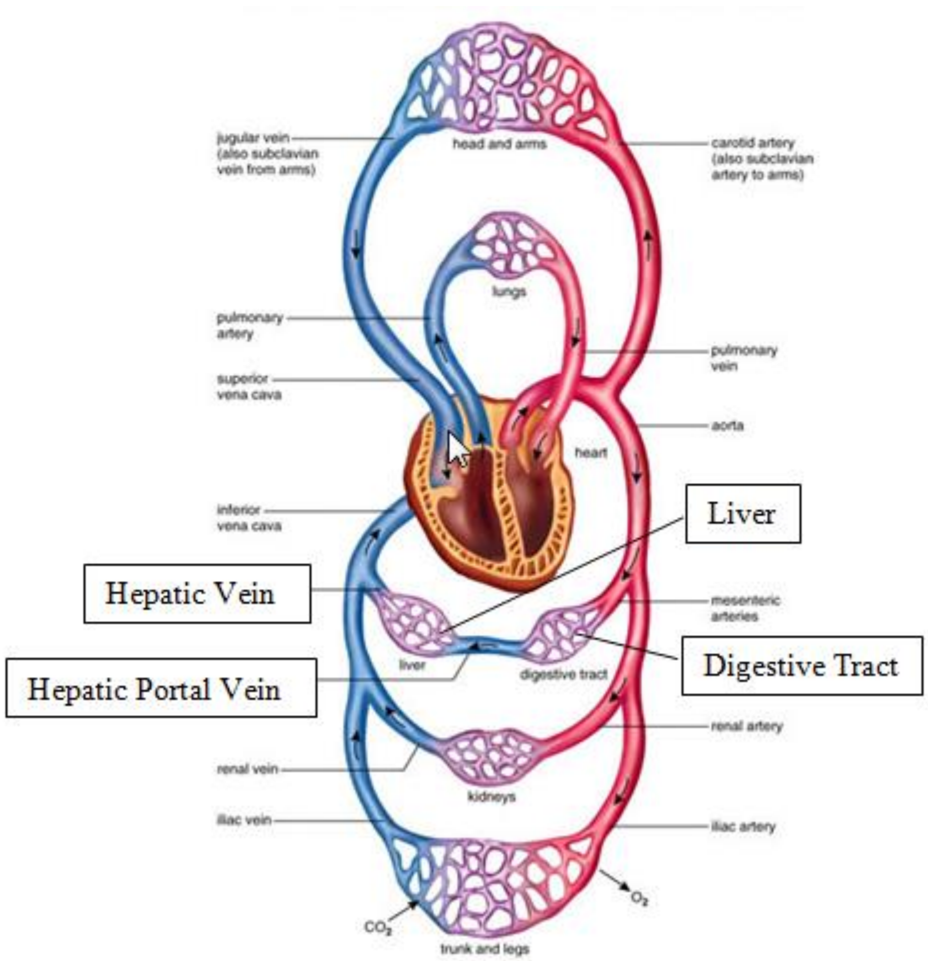


Figure 4
Image Courtesy of McGraw-Hill Companies. Permission granted for display.

37. Your fingertip is an extra sensitive part of your skin due to specialized nerve cells called:

a. Motor Neurons
b. Sensory Neurons
c. Interneurons

38. The reason for my answer is because:

a. Sensory neurons extend from the fingertip straight to the brain
b. Interneurons generate nerve impulse that are action potentials which involve the uninterrupted exchange of ions (Na+ and K+) through gates along the length of a neuron.
c. Skin areas are more sensitive because certain areas are more densely packed with sensory neurons
d. Motor neurons detect the slightest movements making certain areas of the skin ultra-sensitive.
e. Touch feelings are interpreted via interneurons in the spinal cord which allows for quick interpretation of senses and maximum sensitivity

39. The medulla oblongata of the brain is responsible for all the reflexes that occur in our body in response to some sensory nerve stimulation.

a. This statement is true
b. This statement is false

40. The reason for my answer is because:

a. Spinal reflexes are directed by the medulla oblongata of the brain. Nerve impulses travel to the brain for interpretation and a response is sent via the interneurons to the center in the spine for spinal reflexes
b. The medulla oblongata is responsible for the reflexes of the body such as the blinking reflex, the coughing reflex and the knee jerk reflex
c. Some reflexes require conscious control which involves the medulla oblongata and specialized centers within the spine
d. Reflexes can be spinal reflexes or brain reflexes. With spinal reflexes sensory information goes to the spinal interneurons which transmit signals to the motor neurons bringing about the body reflex

Appendix B – Assessing Attitude Toward Science In General

Germann (1988)

Please use this scale to answer the following questions:

A - Agree
N - Neither agree nor disagree
D - Disagree
SA - Strongly agree
SD - Strongly disagree

(Circle one choice.)

(1) SA A N D SD	Science is fun.
(2) SA A N D SD	I do not like science and it bothers me to have to study it.
(3) SA A N D SD	During science class, I usually am interested.
(4) SA A N D SD	I would like to learn more about science.
(5) SA A N D SD	If I knew I would never go to science class again, I would feel sad.
(6) SA A N D SD	Science is interesting to me and I enjoy it.
(7) SA A N D SD	Science makes me feel uncomfortable, restless, irritable, and impatient.
(8) SA A N D SD	Science is fascinating and fun.
(9) SA A N D SD	The feeling that I have towards science is a good feeling.
(10) SA A N D SD	When I hear the word science, I have a feeling of dislike.
(11) SA A N D SD	Science is a topic which I enjoy studying.
(12) SA A N D SD	I feel at ease with science and I like it very much.
(13) SA A N D SD	I feel a definite positive reaction to science.
(14) SA A N D SD	Science is boring.

APPENDIX C – ASSESSING ATTITUDE TOWARD STYLE OF SCIENCE TEACHING

Please use this scale to answer the following questions:

A - Agree
N - Neither agree nor disagree
D - Disagree
SA - Strongly agree
SD - Strongly disagree

(Circle one choice.)

(1) SA A N D SD	I like a lecture style of teaching.
(2) SA A N D SD	I prefer an instructor to be a "guide by the side" instead of a dispenser of knowledge.
(3) SA A N D SD	I feel prepared for tests after learning under a lecture style of teaching.
(4) SA A N D SD	Activities in class should encourage students to develop their own ideas about content.
(5) SA A N D SD	Facts, concepts, and principles are the most important things that students should acquire.
(6) SA A N D SD	During laboratory exercises I like to follow a step-by-step procedure.
(7) SA A N D SD	Laboratory exercises makes me feel uncomfortable, restless, irritable, and impatient.
(8) SA A N D SD	I prefer a limited amount of guidance during laboratory exercises.
(9) SA A N D SD	I prefer small group discussions to talk about discoveries made in class.
(10) SA A N D SD	I feel I learn best under a lecture style of teaching.
(11) SA A N D SD	I like forming my own questions and designing my own investigations in science class.
(12) SA A N D SD	I like lecture explanation followed by a lab to confirm what I was explained to me.
(13) SA A N D SD	I feel I learn best when I make discoveries on my own.
(14) SA A N D SD	I prefer to explore & discover scientific phenomenon before it is explained to me.
(15) SA A N D SD	Learning occurs the most when students set their own pace for completing independent and/or group projects.
(16) SA A N D SD	I can remember more about a subject through a lecture method with information & explanations dispensed to me.

Appendix D – Sample Of The Focus Group Interview Questions Targeting Attitude And Content

Attitude

1. After taking this course, do you feel you have a more negative or positive attitude toward taking science classes in general?

2. Describe a course format in which you feel you have learned the most.

3. How does this relate to this science course (or other science courses)?

4. What did you like about the structure of the labs/course?

5. Have you experienced a science class where you were able to solve problems on your own—how did you learn in this situation?

6. How did you feel when I just gave you a question and had you work with your group to determine the answer?

7. During laboratory exercises do you like to follow a step-by-step procedure or do you like forming your own questions and designing your own investigations in science class?

Content

8. Explain the role of objectivity in scientific explanation:

9. Explain the difference between dependent and independent variables:

10. How do you picture the diffusion of atoms happening?

11. How do deviations from an enzymes optimal pH and temperature affect its structure and function? Explain:

12. Antibiotics target which germs? How do they work?

13. What is the reason why you breathe faster when you begin to exercise?

14. Can an animal heart beat when separated from the brain? Explain?

15. Is it normal to find some glucose in the urine of an individual? Explain:

Appendix E – EQUIP Rubric

IV. Instructional Factors					
Construct Measured		*Pre-Inquiry (Level 1)*	*Developing Inquiry (2)*	*Proficient Inquiry (3)*	*Exemplary Inquiry (4)*
I1.	Instructional Strategies	Teacher predominantly lectured to cover content.	Teacher **frequently lectured** and/or used demonstrations to explain content. Activities were **verification only**.	Teacher **occasionally lectured**, but **students were engaged in activities** that helped develop conceptual understanding.	Teacher occasionally lectured, but students were engaged in investigations that **promoted strong conceptual understanding**.
I2.	Order of Instruction	Teacher explained concepts. Students either did not explore concepts or did so only after explanation.	Teacher asked **students to explore concept before receiving explanation**. Teacher explained.	Teacher asked students to **explore before explanation**. **Teacher and students explained**.	Teacher asked students to explore concept before explanation occurred. Though perhaps prompted by the teacher, **students provided the explanation**.
I3.	Teacher Role	Teacher was center of lesson; rarely acted as facilitator.	**Teacher was center of** lesson; **occasionally** acted as **facilitator**.	Teacher **frequently** acted as facilitator.	Teacher **consistently and effectively** acted as a facilitator.
I4.	Student Role	Students were consistently passive as learners (taking notes, practicing on their own).	**Students were active to a small extent** as learners (highly engaged for very brief moments or to a small extent throughout lesson).	**Students were active** as **learners** (involved in discussions, investigations, or activities, but not consistently and clearly focused).	Students were **consistently and effectively active as learners** (highly engaged at multiple points during lesson and clearly focused on the task).
I5.	Knowledge Acquisition	Student learning focused solely on mastery of facts, information, and/or rote processes.	Student learning focused on **mastery of facts** and process skills without much focus on understanding of content.	Student learning required **application of concepts** and process skills in new situations.	Student learning required **depth of understanding** to be demonstrated relating to content and process skills.

V. Discourse Factors					
Construct Measured		*Pre-Inquiry (Level 1)*	*Developing Inquiry (2)*	*Proficient Inquiry (3)*	*Exemplary Inquiry (4)*
D1.	Questioning Level	Questioning rarely challenged students above the remembering level.	Questioning rarely challenged students above the **understanding level**.	Questioning challenged students **up to application** or **analysis levels**.	Questioning challenged students at various levels, **including at the analysis level or higher; level was varied to scaffold learning.**
D2.	Complexity of Questions	Questions focused on one correct answer; typically short answer responses.	Questions focused **mostly on one correct answer**; some open response opportunities.	Questions **challenged students to explain, reason, and/or justify**.	Questions required students to explain, reason, and/or justify. **Students were expected to critique others' responses.**
D3.	Questioning Ecology	Teacher lectured or engaged students in oral questioning that did not lead to discussion.	Teacher occasionally **attempted to engage students in discussions** or **investigations but was not** successful.	Teacher **successfully engaged students** in open-ended questions, discussions, and/or investigations.	Teacher **consistently and effectively engaged students** in open-ended questions, discussions, investigations, and/or reflections.
D4.	Communication Pattern	Communication was controlled and directed by teacher and followed a didactic pattern.	Communication was **typically controlled and directed by teacher** with occasional input from other students; mostly didactic pattern.	**Communication was often conversational** with some student questions guiding the discussion.	Communication was **consistently conversational with student questions often guiding the discussion.**
D5.	Classroom Interactions	Teacher accepted answers, correcting when necessary, but rarely followed-up with further probing.	Teacher or another student **occasionally followed-up student response** with further low-level probe.	Teacher or another student **often followed-up response** with engaging probe that required student to justify **reasoning or evidence.**	**Teacher consistently and effectively facilitated rich classroom dialogue** where evidence, assumptions, and reasoning were challenged by teacher or other students.

VI. *Assessment Factors*					
Construct Measured		*Pre-Inquiry (Level 1)*	*Developing Inquiry (2)*	*Proficient Inquiry (3)*	*Exemplary Inquiry (4)*
A1.	Prior Knowledge	Teacher did not assess student prior knowledge.	Teacher **assessed student prior knowledge but did not modify instruction** based on this knowledge.	Teacher assessed student prior knowledge and then **partially modified instruction** based on this knowledge.	Teacher assessed student prior knowledge and then **modified instruction** based on this knowledge.
A2.	Conceptual Development	Teacher encouraged learning by memorization and repetition.	Teacher encouraged **product- or answer-focused** learning activities that **lacked critical thinking.**	Teacher encouraged **process-focused** learning activities that **required critical thinking**.	Teacher encouraged process-focused learning activities that involved **critical thinking that connected learning with other concepts**.
A3.	Student Reflection	Teacher did not explicitly encourage students to reflect on their own learning.	Teacher explicitly encouraged students to **reflect** on their learning but only at a minimal **knowledge level**.	Teacher explicitly encouraged students to **reflect** on their learning at an **understanding level**.	Teacher consistently encouraged students to reflect on their learning at multiple times throughout the lesson; **encouraged students to think at higher levels**.
A4.	Assessment Type	Formal and informal assessments measured only factual, discrete knowledge.	Formal and informal assessments **measured mostly factual, discrete knowledge**.	Formal and informal assessments **used both factual, discrete knowledge and authentic measures**.	Formal and informal assessment methods **consistently and effectively used authentic measures**.
A5.	Role of Assessing	Teacher solicited predetermined answers from students requiring little explanation or justification.	Teacher **solicited information from students** to assess understanding.	Teacher solicited explanations from students to assess **understanding and then adjusted instruction** accordingly.	Teacher frequently and effectively assessed student understanding and adjusted instruction accordingly; **challenged evidence and claims made; encouraged curiosity and openness**.

VII. Curriculum Factors					
Construct Measured		*Pre-Inquiry (Level 1)*	*Developing Inquiry (2)*	*Proficient Inquiry (3)*	*Exemplary Inquiry (4)*
C1.	Content Depth	Lesson provided only superficial coverage of content.	Lesson provided **some depth** of content but with **no connections made to the big picture.**	Lesson provided depth of content with **some significant connection** to the big picture.	Lesson provided depth of content with **significant, clear, and explicit connections** made to the big picture.
C2.	Learner Centrality	Lesson did not engage learner in activities or investigations.	Lesson provided **prescribed activities** with anticipated results.	Lesson allowed for **some flexibility during investigation** for student-designed exploration.	Lesson provided **flexibility for students to design and carry out** their own investigations.
C3.	Integration of Content and Investigation	Lesson either content-focused or activity-focused but not both.	Lesson provided poor integration of content with activity or investigation.	Lesson **incorporated student investigation that linked well with content.**	Lesson **seamlessly integrated the content and the student investigation.**
C4.	Organizing & Recording Information	Students organized and recorded information in prescriptive ways.	**Students had only minor input as to how to organize and record information.**	Students regularly organized and recorded information in **non-prescriptive ways**.	Students organized and recorded information in **non-prescriptive** ways that allowed them to **effectively communicate their learning.**

*EQUIP Tool Images Courtesy of Marshall et al. (2009). Permission granted for display.

APPENDIX F – INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

UNIVERSITY OF SOUTH CAROLINA

OFFICE OF RESEARCH COMPLIANCE

August 27, 2012

Mr. Daniel Kiernan
USC Sumter
Division of Mathematics, Science & Engineering
200 Miller Road, Schwartz Bldg., Rm 108
Sumter, SC 29150

Re: **Pro00017861**
Study Title: *Inquiry-Based Teaching in the College Classroom: The Nontraditional Student*

FYI: University of South Carolina Assurance number: FWA 00000404 / IRB Registration number: 00000240

Dear Mr. Kiernan:

In accordance with 45 CFR 46.101(b)(**1**), the referenced study received an exemption from Human Research Subject Regulations on **8/23/2012.** No further action or Institutional Review Board (IRB) oversight is required, as long as the project remains the same. However, you must inform this office of any changes in procedures involving human subjects. Changes to the current research protocol could result in a reclassification of the study and further review by the IRB.

Because this project was determined to be exempt from further IRB oversight, consent document(s), if applicable, are not stamped with an expiration date.

Research related records should be retained for a minimum of three years after termination of the study.

The Office of Research Compliance is an administrative office that supports the USC Institutional Review Board. If you have questions, please contact Arlene McWhorter at arlenem@sc.edu or (803) 777-7095.

Sincerely,

Thomas A. Coggins
Director

cc: Christine Looter