Let them design it! The effects of inquiry-based activities on AP biology students.

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Introduction

Over the past years there has been a general push in science education to move towards inquiry-based methods of teaching as a means of getting students to develop deeper understanding of scientific concepts and to sharpen their higher-order critical thinking skills. "Inquiry-based learning is a student-centered, active learning approach focused on questioning, critical thinking, and problem solving" (Savery, 2006). This approach requires teachers to step away from the traditional teacher-centered model where direct instruction through lecture is the predominant method of instruction. It rejects the idea that science is a large body of knowledge consisting of principles and facts that need to be memorized. Instead, with this instructional approach teachers can embrace a more student-centered style that allows students an opportunity to be more actively involved in their own learning experience.

Research Question

For my research study, I am interested in observing and exploring the effects that inquiry-based learning and instruction will have on my students' level of engagement, achievement in science, and in their attitude towards science. My research question is: What happens when I incorporate inquiry-based activities in my AP Biology class? The over-arching theme of my research is student engagement and some of the sub-questions I am interested in exploring include: How do inquiry based activities affect student comprehension of scientific content? What effect does participation in an inquiry activity have on student engagement? How does participation in inquiry activities impact student confidence in their ability to do and understand science? How does inquiry impact their overall attitude towards science class?

Educational Setting and Context

Hanover Park High School is a small regional high school in Morris county which serves approximately 825 students in grades 9^{th} through 12^{th}. I have been a science teacher in this district for ten years and teach various levels of general biology courses to students ranging in academic readiness from in-class support, to college prep, to honors, to advanced placement (AP). In addition, I also teach an anatomy & physiology course to juniors and an ecology course to freshman. Due to the range in levels and differences in subject matter that I teach, I chose the focus of my research project to be on my AP biology classroom with my 12^{th} grade students. In addition, the curricular framework for AP biology is centered on developing enduring understandings of four fundamental biological concepts: evolution, cellular processes, genetics/information transfer, and interactions, which lends itself nicely to a more student centered inquiry-based instructional approach. According to the National Science Education Standards, "Studying biology means practicing the skills of posing problems, generating hypotheses, designing experiments, observing nature, testing hypotheses, interpreting and evaluating data, and determining how to follow up on the findings" (NRC, 2000). These are all skills that are central to the process of inquiry.

AP Biology at my school is an elective course offered to students that have successfully completed one year of general biology and one year of general chemistry. Students who choose to enroll in this course must have performed well (at least a B average or above) in both courses, biology and chemistry, in order to be granted permission to register. Even though there is a pre-requisite in place and the students are labeled as "advanced", based on my experience from working with them in the classroom I would state that the class is heterogeneously grouped. Currently, in the class there are a total of 24 students (17 females and 7 males) from various ethnic backgrounds. The course is designed to mirror an introductory biology course usually taken by science majors during their first year in college. If the students score a 5 or 4 on the AP exam in May, then they have the possibility of being exempt from taking general biology as first year undergraduate students in college. As a result, the students in my class are held to a rigorous curriculum and high expectations. The class meets six periods each week for forty-three minute periods. The laboratory component of the course is essential to the curricular framework, big ideas, and enduring understandings for this class.

By inquiry-based activities, I am referring to activities that are more "authentic" in nature and that require students to take a similar role to that of a scientist working in a real world setting as a member of the scientific community. "Inquiry-based learning is frequently used in science education and encourages a hands-on approach where students practice the scientific method on authentic problems" (Savery, 2006). My district has placed strong emphasis on the need to incorporate and promote authentic inquiry-based activities into our classrooms and science curricula. As a result, I have begun to implement some of these activities in my classes. I often find myself wondering if these authentic experiences are more valuable and meaningful to the students than those that I would use with a more traditional method of instruction. In 4*0 Inquiry Exercises for the College Biology Lab*, Johnson (2009) presents the results of various studies conducted on the use of inquiry and recommendations made by the National Research Council (NRC) suggesting that when students learn science through an active hands-on approach, like inquiry-based instruction, they learn more and can retain knowledge longer. I also wonder about my students' feelings towards inquiry. Do they feel more confident in their ability to do science? Are they more engaged with the content? Do the activities help them understand the material better? Do they like my class or science better because they are involved in inquiry-based learning?

I have a strong interest in this topic and care deeply about it because I am a strong believer that as individuals, we learn by doing, from concrete experience, by experimenting and by making mistakes. My pedagogical beliefs are grounded on the constructivism learning theory based on the work of Piaget and Vygotsky, which suggests we are active creators of our own knowledge (Thirteen Ed Online, 2004). Students come into a learning situation with preexisting ideas and knowledge and as they work through new situations they will acquire new knowledge by modifying their preexisting ideas. Johnson (2009) explains that with a constructivist view to education the responsibility of learning lies with the learner and the instructor becomes a facilitator in the learning process. "Constructivism transforms today's classrooms into a knowledge-construction site where information is absorbed and knowledge is built by the learner" (Ozer. O, 2004).

For me, it is important that my students find meaning and value in what they are learning and that they can visualize the connection between the information, knowledge, and skills they acquire in my classroom to their own lives. I want them to feel engaged, be willing to take risks, and push themselves outside their comfort zone to attempt new and challenging tasks. In accordance with the Vygotskian concept of the Zone of Proximal Development (ZPD), the most effective instruction occurs when a student is in the ZPD for a particular task or activity. McLeod (2010) cites Vygotsky's definition of ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers". When students are engaged with inquiry-based activities they are working within their ZPD and as a result this instructional approach can lead to significant gains in student understanding and learning. This is why I have begun playing with inquiry and I am very interested in seeing whether it can be an effective instructional strategy for me. Many of the courses that I teach, especially AP biology, are so heavily content driven that I often struggle with finding the right balance between infusing inquiry-based activities into my teaching and getting through all the required content in the curriculum. In doing this research project, I hope to explore the effects that stepping away from the lecture and embracing a more student-centered inquiry approach will have on my students and myself.

Literature Review

The use of inquiry-based instruction methods to teach science has been a topic that has gained much attention and popularity among science educators within the last few years. In researching my topic, I had the opportunity to review articles, interpret current research studies and synthesize their findings to help me explore my own research question: What happens when I incorporate inquiry-based activities in my AP Biology class? I discovered that a considerable amount of research has been done over the years to explore the effectiveness of using inquiry methods in a science classroom, yet there is still some debate about its effectiveness to improve learning.

Some of the past research in the field regarding the use of inquiry-based instructional methods has looked at student engagement, academic achievement, attitudes, and student confidence. One of the studies I reviewed focused on the use of inquiry in a laboratory setting and how the implementation of such activities affected students' science literacy skills and confidence (Armstrong et al., 2009). While two other studies, one conducted by Doppelt et al. (2008) and the other by Murray and Summerlee (2010), explored the impact of inquiry based-learning on both, academic achievement and engagement. Some of the common emerging themes across the literature, which were of particular interest to me, were those relating to student engagement, achievement, and attitudes towards science. Each emergent theme from the literature will be discussed in a separate section later in this paper.

It is also worth noting that while some researchers suggest a positive correlation between the use of inquiry-based instructional practices and student outcomes others have a difference of opinion. Clark et al. (2006) state that "the past half-century of empirical research on this issue has provided overwhelming and unambiguous evidence that minimal guidance during instruction is significantly less effective and efficient than guidance specifically designed to support the cognitive processing necessary for learning". They define a minimally guided instructional approach to be one in which students are placed in an inquiry-based learning environment tackling an authentic problem. In their article, they discuss the human cognitive architecture responsible for learning and argue that inquiry-based learning ignores the relationships between working memory and long-term memory and as such it is likely to be an ineffective instructional strategy. Another study conducted by Vogel-Walcutt et al. (2010) compared the effects of using instructional guidance versus a constructivist-based approach, such as inquiry, for teaching a military command and control task. Their research findings suggest that learning improved when students received instructional guidance. "Thus, while contemporary researchers continue to defend the use of constructivist strategies for teaching, our research supports earlier findings that question the utility, efficiency, and impact of these strategies in applied domains" (Vogel-Walcutt et al., 2010).

In Johnson's (2009) experience both approaches, traditional didactic and inquiry-based, can be mixed and used effectively within a course and even during a single lesson or laboratory session. Similarly to Clark et al. (2006), Johnson (2009) believes that to completely abandon the traditional didactic, content-centered method of instruction would be a terrible mistake since there may be times when this method of instruction is the most favorable and effective. However, contrary to Clark et al. (2006), Johnson (2009) supports the use of inquiry methods to teach science and suggests that it can foster deep, meaningful learning for students. He explores human learning patterns and states, "neither didacticism nor inquiry is fundamentally better, they represent two different sets of teaching tools, and each set can achieve certain instructional goals very effectively" (Johnson, 2009, p 11). Willingham and Rotherman (2009) suggest that knowledge and skills are not separate entities, but rather are deeply intertwined with each other and in order to think critically students need specific knowledge. This implies that curriculum cannot be based solely on skills and supports Johnson's notion that both didacticism and inquiry can have their time and place in schools. Furthermore, Willingham (2004) explains factual knowledge is part of the goal of schooling, but the larger goal is to develop students that are good at problem solving and thinking-critically. He suggests that thinking skills become automatic through repeated practice and when this "automaticity" results these skills no longer take up space in working memory freeing it up to do higher-level thinking (Willingham, 2004). "Students need exposure to varied examples before their understanding of a concept becomes more abstract and they can successfully apply that understanding to novel situations" (Willingham & Rotherman, 2009).

In the next section, student engagement, I will describe what current literature and recent studies have found regarding student engagement in relationship to inquiry. This section will provide a description of the three dimensions of engagement, how researchers have defined and measured engagement in their studies, and explain the "SCORE" model of student engagement. In addition, this section will summarize the key findings of each of the studies presented.

Student Engagement

One of the recurring themes across various pieces of literature was that of student engagement and how it was affected by the use of inquiry-based activities. A high level of engagement among the student body has been linked to a higher level of academic achievement (Fredericks et al., 2011). As a result, educators and researchers have focused more attention on student engagement in order to gain a better understanding. Fredericks et al. (2011) describe engagement as having three critical dimensions that interact with each other. These three dimensions include: behavioral engagement (participation in school work and extra-curricular activities), emotional engagement (relationships with peers and teachers), and cognitive engagement (student's effort and investment).

Murray and Summerlee (2010) describe engagement in a similar way. They measured engagement by the number of times students participate in class discussion, questions they asked, body language, how they worked with other students, comments made to their peers, and time students spent volunteering in the community (both within the school and outside the school). The researchers tracked a group of first-year university students throughout their undergraduate program to gather data on how participation in an inquiry-based course influenced their engagement. During the course, students were presented with scenarios and then required to identify issues and research principles to learn the material in context. Murray and Summerlee (2010) report that students who participated in the inquiry-based learning seminar compared to students in the control group had a higher level of engagement. Another study conducted by Baptista et al., (2012) trying to understand how to promote engagement in science for students who were at risk of dropping out shared similar results. The researchers found that when students were involved in inquiry modules that presented them with an authentic learning opportunity in which they were able to connect science with something of personal meaning their interest levels peaked (Baptista et al., 2012). As a result, the students were more likely to engage in the learning episode.

Johnson (2009) believes that this increased level of student engagement during inquiry-based activities comes about because inquiry-centered instructional methods encourage students to be active participants in the discovery of knowledge. Students' level of thinking is elevated because in order to succeed the students need to be deeply engaged in trying to make sense of the content. In addition, with inquiry activities there are no predetermined results or solutions that the students must come to. Students must examine and reflect on their observations and understandings all leading to a higher level of engagement. "Problem-based learning is an instructional learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006). Savery refers to students involved in this type of inquiry as "engaged problem solvers." In addition, Savery (2006) presents the following features as described by the Problem-Based Learning Initiative as essential characteristics for inquiry and problem-based activities:

- Students must have the responsibility for their own learning.
- The problem simulations used in problem-based learning must be ill-structured and allow for free inquiry.
- Learning should be integrated from a wide range of disciplines or subjects.
- Collaboration is essential.
- What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution.
- A closing analysis of what has been learned from work with the problem and a discussion of what concepts and principles have been learned are essential.
- Self and peer assessment should be carried out at the completion of each problem.
- The activities carried out in problem-based learning must be those valued in the real world.

Many of these essential characteristics for inquiry were incorporated into the eight steps of the module design inquiry activity that students were asked to complete in this next case study (Doppelt et al., 2008). The researchers examined two middle school science classrooms (low-level and high-level) taught by the same teacher who adopted an open design-based inquiry approach. Doppelt et al. (2008) were interested in seeing if students labeled high and low achievers could become equally engaged by the inquiry design. The findings suggest that students perceived to be low-achieving displayed a higher level of engagement during the authentic learning episode than the higher achieving class. The study observer noted "students who previously had problems paying attention in class and remaining engaged were attentive and fully engaged during the implementation of the design module" (Doppelt et al., 2008).

Robinson et al. (1995) describe a model of student engagement with the acronym "SCORE". According to their research, when individuals are engaged in their work they are driven by four major goals, with each one meeting a basic human need. The goals are as follows:

- Success (need for mastery)
- Curiosity (need for understanding)
- Originality (need for self-expression)
- Relationships (need for involvement with others)

The "E" stands for energy with the idea being that if these four goals are met during the learning episode for each student, then they will feel energized and motivated (Robinson et al., 1995).

The next section, student achievement, presents statistics of a public opinion poll regarding the importance of science and compares them to those from the National Assessment of Educational Progress (NAEP) suggesting there's a disconnect between the two. In addition, it describes the types of studies and their findings currently being conducted in the field to determine if inquiry is an effective instructional strategy to increase student achievement and understanding in science. This section will also describe the theory of cognitive constructivism as a pedagogical concept relating to inquiry and distinguish between a fixed mindset versus a growth mindset.

Student Achievement

Getting students to perform better in school is a goal of all stakeholders involved in education. How do kids learn best? What type of instructional strategies should be used in the classroom to maximize learning? "If we are going to increase student performance, we must diligently focus our schools on the one critical factor that has the greatest impact on student achievement – classroom instruction" (O'Connor, 2009). Most Americans agree that science education and achievement is very important for our nations future. According to the 2011 National Public Opinion Poll, when asked "How important do you think education and training in science, technology, engineering and mathematics is to U.S. competitiveness and our future economic prosperity?" 74% said very important; 24% somewhat important; and 2% said not too important (Research America, 2011). However, public opinion does match current levels of student achievement in the field. According to the 2011 National Assessment of Educational Progress (NAEP) in science, which measures the knowledge and skills students have acquired in their science education, sixty-five percent of eighth-graders performed at or above "basic", thirty-two percent performed at or above "proficient", and only 2 percent of students performed at the "advanced level" (NAEP, 2011). These statistics suggest that there is a need to find effective instructional strategies in science to help educators to increase achievement.

Some of the literature suggests that inquiry-based strategies in teaching science can help educators increase student achievement and challenge student thinking. Johnson (2009) believes that inquiry challenges students' pre-existing mental models for learning. Hartle et al. (2012) describe the theory of cognitive constructivism and state "this is a learning theory that describes learning as taking new ideas or experiences and fitting them into a complex system that includes the learner's entire prior learning" (Harlte et al., 2012). According to Johnson (2009), this is the reason why inquiry, a constructivist teaching method, can foster deeper, more functional and meaningful learning. He stresses that one of the drawbacks of using only traditional didactic methods of instruction is that it can lead to "shallow learning". "Deeper learning occurs when a learner faces a question, problem, or situation that his or her current mental models fail completely to resolve" (Johnson, 2009, p. 7). This type of learning is the type students experience when taught through inquiry.

On the other hand, Clark et al. (2006) maintain that since inquiry-instruction doesn't allow for the learner to rely on pre-existing mental models and prior experiences stored in long-term memory it is unlikely to support meaningful learning. Hartle et al. (2006) refer to this concept as "cognitive dissonance" and argue that it is often when a student realizes that their prior constructs or mental models do not meet their current needs that they will be motivated to learn new information and acquire new knowledge. "In order to learn, neural connections must be broken and remade which takes time, uses energy, and requires effort" (Hartle et al. 2006). In their field guide to using constructivism in the science classroom, Hartle et al (2006) caution that too much cognitive dissonance will be counterproductive to meaningful learning because it will turn the learner off and too little cognitive dissonance will not motivate the learner to change prior knowledge.

Clark et al. (2006) describe a number of controlled experimental studies that support a direct instructional guidance approach. According to them, emphasis on inquiry and authentic learning appears attractive, but there is no evidence that presenting students with partial information enhances their learning more than giving them full information and guidance (Clark et al., 2006). "Controlled experiments almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it" (Clark et al., 2006). They site the work of various researchers (Moreno, 2004; Tuovinen & Sweller, 1999; Brown and Campione, 1994) that found students learning science through inquiry methods often became frustrated, confused, and developed misconceptions, which suggests that students learn more deeply through guided learning versus discovery (Clark et al., 2006). Dweck (2010) believes that student mindsets are the driving force in determining whether a student works hard or simply gives up when faced with adversity. She describes the two mindsets as a “fixed mindset” or “growth mindset”. Students with fixed mindsets believe that their intelligence is set and innate while those with growth mindsets believe that intelligence can be developed with hard work and effort and as a result view challenges as opportunities for growth (Dweck, 2010). She states that our role as educators is to design meaningful learning tasks and create a classroom culture that encourages the growth mindset. “Our research shows that if students can be redirected to see intellectual ability as something that can be developed over time with effort, good strategies, and help from others, then they are more resilient when they encounter the rigorous learning opportunities presented to them” (Yeager & Dweck, 2012).

In support of inquiry, the NAEP 2011 science assessment results showed that students involved in frequent hands-on scientific investigations within their science curriculum scored higher on average than those students who participated in them less frequently (NAEP, 2011). As discussed in the engagement section of this paper, research has suggested that there is a link between engagement and student achievement. “Engaged students are more likely to earn better grades and perform well on standardized tests” (Fredericks et al., 2011). Murray and Summerlee (2010) reported an increase in engagement when they explored the effects of inquiry-based learning on their cohort of students. Likewise, when they tracked this same cohort to explore how participation on an inquiry-based course impacted their subsequent academic performance they found that these students had statistically significant higher academic performance than those in the control group (Murray & Summerlee, 2010). Furthermore, their data revealed that students stratified into the lowest academic group based on their grades upon admission had the highest overall improvement in academic performance. These findings are consistent with the results of the study conducted by Doppelt et al. (2008), which found students involved in inquiry-design modules showed increased achievement. However, their results from pre- and post- knowledge tests for high-achieving and low-achieving groups showed that although the low-achievers improved in their post-test scores, their gains were not as significant as the high-achieving group (Doppelt et al., 2008). Armstrong et al. (2009) also demonstrated a greater improvement in science literacy and science process skills in students who participated in an inquiry based laboratory biology course as compared to students who enrolled in a traditional biology laboratory curriculum. The researchers report that inquiry and traditional lab students performed similarly on the pre-test for the science literacy assessment, but in their analysis of the post-test results the inquiry lab students performed significantly higher than traditional lab students (Armstrong et al., 2009).

The next section, student attitudes and confidence, summarizes the data trend of students entering scientific fields and describes the relationship between a hands-on science curriculum and attitudes towards science. In addition, it describes and summarizes research findings about science attitudes resulting form experience with an inquiry-based laboratory setting and describes how this experience impacted students' confidence in their perceived ability to perform scientific tasks.

Student Attitudes and Confidence

Research suggests that the use of inquiry activities and project-based learning in instruction has the potential to increase retention of content and also improve students' attitudes towards learning (Vega, 2012). Osborne et al. (2003) reviewed literature on students' attitudes towards science in an attempt to understand its implications in relation to the decline that many countries are seeing in the number of students choosing to pursue scientific careers (Osborne et al., 2003). They propose that "attitudes towards science" are difficult to understand since there is a somewhat vague concept of what it entails. However, they argue that due to the decrease in students entering scientific fields this area warrants further research to help gain a better understanding of the problem and find remediation (Osborne et al., 2003). They also present findings, which suggest that science curricula that relates to students' interest and provides a more hands-on experience results in positive attitudes towards school science (Osborne et al., 2003).

Using an inquiry hands-on approach in a biology laboratory course, Armstrong et al. (2009) set out to investigate if inquiry during an entire semester in a lab setting could alter students' attitudes and confidence in their ability to do science. Johnson (2009) presents a snapshot of student attitudes from the Howard Hughes Medical Institute (HHMI) report (1998) stating that Biology students approach their laboratory sessions with mixed emotions. Some students view their lab experience as an opportunity for discovery and research, while others view it a useless exercise where they come up with known answers to some already generally accepted scientific principle (Johnson, 2009). The approach adopted by Armstrong et al. (2009) in their study was one of presenting students with a challenge by having them do inquiry labs in which they pursued their own research.

The investigators reported that when compared to the traditional lab group the inquiry lab group students reported a lower self-confidence in their ability to do science than the students in the traditional lab setting (Armstrong et al., 2009). In addition, during students' interviews to assess student attitudes about the inquiry labs in comparison to the traditional labs those students who were enrolled in the traditional laboratory courses rated their overall lab experience significantly higher than the group who performed the inquiry labs (Armstrong et al., 2009). Some of the negative attitudes pertaining to their inquiry lab experience were associated with feelings of frustration as they struggled to figure out content, fear of failure, and the amount of work associated with an inquiry design approach to labs. These types of negative student attitudes and concerns are similar to those sited previously by Clark et al. (2006) in their argument as to why a minimally guided instructional approach is ineffective. They felt that students could develop misconceptions, which could ultimately impede learning (Clark et al., 2006). Johnson (2009) argues that students' negative attitudes towards inquiry result because students are comfortable and accustomed to their passive roles as learners. Inquiry represents a new way of thinking for students that make them uncomfortable, at least initially, and that's why students are likely to have a negative attitude and complain about inquiry (Johnson, 2009).

An underlying theme and question behind many of the studies reviewed is whether or not an inquiry-based approach to teaching science is an effective instructional strategy to meet the needs of students and maximize their learning. Although many researchers seemed to support a positive correlation between inquiry and engagement, and inquiry and achievement, the same was not true for students' attitudes and confidence in their self-evaluation of scientific ability. Some researchers question the validity of inquiry-based instruction by arguing that it violates our human "cognitive architecture" (Clark et al., 2006). As a science educator, I want to provide my students with the best possible learning experience. I want to make the learning meaningful and ignite my students' passion for science. I am eager to learn how incorporating inquiry instruction will impact my own classroom and how my findings will compare to the findings of those before me.

Methodology

Study Objective

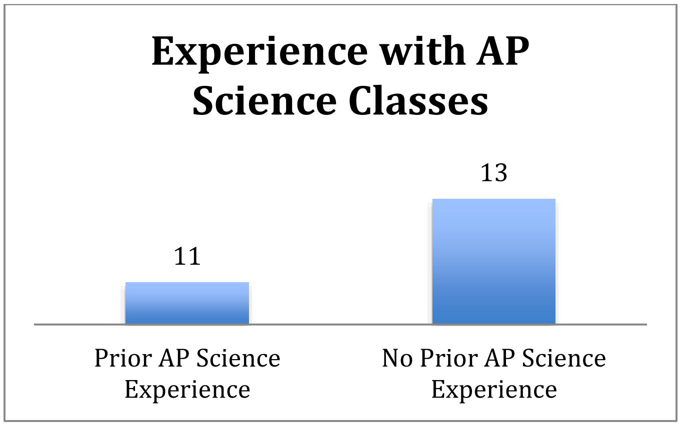
The objective of my research project was to allow me the opportunity to explore the overarching theme of student engagement in relationship to the use of inquiry-based activities in my classroom. For the purposes of my research project, I defined inquiry-based activities to be those that encouraged and invited students to deepen their understanding of scientific concepts by discovering content and acquiring knowledge for themselves as they explored and experimented with ideas they found meaningful and interesting. This philosophical view is grounded on the work and constructivist theories of Jean Piaget (1896-1980) and Lev Vygotsky (1896-1934), which suggest that learning is based on students' active participation and social collaboration in learning experiences they find meaningful and as such the learners "construct" their own knowledge and comprehension (Ozer O., 2004). According to the National Science Education Standards, "Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 2000).

In this study, I was especially interested in seeing how participation in inquiry-based activities would affect my students' understanding of science and their attitudes towards science. As a result, when deciding how to set up the research component I knew that I wanted to document students' behaviors during the learning episode with regards to their level of engagement, their understanding of scientific information or concepts, their attitudes towards science, and views about their confidence to complete scientific tasks. To determine if students were engaged during inquiry I observed behaviors pertaining to body language (establishing eye contact, paying attention, sitting up, doodling, pensive, daydreaming), class participation (asking questions, staying on task), intellectual investment (formulating questions to investigate, coming up with a hypothesis and procedure, trouble-shooting, problem-solving, and manipulating lab equipment), and communicating with other students. Student attitudes were measured based on the level of enjoyment and interest in science as reported by the students in exit-slip questionnaires, self-assessment survey, and student interviews. Student responses suggesting enjoyment or interest in science will be interpreted as favorable or positive attitudes towards science. Throughout the course of a ten-week period I collected a variety of data sources to inform my research: personal journals/reflections, exit slip questionnaires, field notes/classroom observations, student grades, science skills self-assessment survey, and student interviews.

Study Participants

The participants of my research project were twenty-four 12th grade students enrolled in my AP Biology course. Based on my experience from working with these students for six months and from conversations we have had in-class, my impression is that students in this course have a varying degree of interest in science ranging from high to low. Some students have a higher level of academic readiness because they have a strong foundation in science from their experience with prior AP science classes. On the other hand, others struggle with content and the demands of the course because they lack a strong science foundation, pre-requisite knowledge, and this is their first experience with an AP level science course.

Figure 1: Summary of students' prior AP science experience (n=24).



Time was a factor that I took into consideration when selecting my AP class as the sample for my project. I see the students every day during 7th period for a total of 43 minutes. On Tuesdays, students take the lab component of the course and stay for an 86 minute-block or 2 consecutive periods. Many of the inquiry activities for my research project took place on Tuesdays due to the extra time allowance for lab and then continued throughout the course of the week. AP Biology is the only course that I teach with a scheduled block period for lab. Logistically, the extra time in lab facilitates the incorporation of inquiry labs and activities into the curriculum. I felt students would have an easier time embracing the inquiry process if given more than one period, since the extra time provides them with more opportunity to develop their thought process, collaborate with others and experiment with different types of apparatus and lab equipment to design their investigations.

By their nature, inquiry-based activities take longer to conduct than traditional ones. As described by Banchi and Bell (2008), inquiry can come in various forms. There are essentially four different levels of inquiry: confirmation inquiry, structured inquiry, guided inquiry, and open inquiry. With each level the students are offered a different amount of support and provided with a different range of information.

Confirmation Inquiry (Level 1): Students confirm a principle through an activity in which the results are known in advance. I provide the students with the question/problem, the step-by-step procedure to follow, and the solution.

Structured Inquiry (Level 2): Students investigate a teacher-presented question through a prescribed procedure. I provide the students with the question/problem and the step-by-step procedure, but do not provide the solution.

Guided Inquiry (Level 3): Students investigate a teacher-presented question using student-designed/selected procedures. I provide the students with only the research question and it is up to them to decide upon the procedure and analyze their data to determine a solution, if one exists.

Open Inquiry (Level 4): Students investigate topic-related questions that are student formulated through student designed/selected procedures. Of the inquiry levels, this is the most authentic since students mimic the work of scientists in a real life laboratory trying to discover knowledge as they observe and explore. I do not provide the students with the question, procedure, or solution.

For the purposes of my research study, I structured the inquiry activities around guided inquiry (level 3) and open inquiry (level 4). The two case studies were guided-inquiry and the three laboratory investigations were open inquiry. I was interested in having the labs transition from the more traditional set-up towards a more open inquiry investigation. In the inquiry labs, students worked in groups of four and they were able to choose their research question to explore, which was framed around a central theme or idea presented in class. It was ultimately up to the students to decide upon which variables to test and why, develop a hypothesis, come up with procedures to test their hypotheses, determine how to analyze their data, and think about how they were going to present and communicate their findings. The inquiry labs were embedded in the middle of the unit and students had already been introduced to some of the more difficult concepts prior to the inquiry activity.

The case studies were more of a problem-based activity. The students worked with a partner and were presented with a problem or real life scenario. They then had to brainstorm, develop a procedure, and decipher through data to propose a scientifically sound explanation to the problem. Their problem-solving and critical thinking skills were challenged and students had to use logical reasoning to communicate their findings and justify their explanations. Both case studies were utilized at the beginning of the unit without any prior introduction to concepts before the inquiry activity.

AP Biology is also a convenient sample for my research since the revised AP biology curriculum framework emphasizes a shift from a traditional teacher directed approach to one that is more student-directed. The course was re-designed by College Board in 2013 to focus more on the development of student enduring understandings of biological concepts rather than memorization of large amounts of content and scientific facts with little meaning to the students. This idea of "depth versus breadth" is in line with the inquiry-based instructional approach I am trying to implement in my classroom to cover the course curriculum.

Research Process

Throughout the course of my ten-week research project the students in my class participated in a total of five inquiry activities: two problem-based case studies and three inquiry-based laboratory investigations. Table 1 outlines the sequence of the inquiry activities performed by topic, the level of inquiry, and the number of periods (43 minutes in length) the students spent working on each activity.

Table 1: Inquiry Activities Completed Throughout Study

Inquiry Activity	Topic	Level of Inquiry	Time
1. Cell-Signaling Case Study	Cell Biology	3 – Guided	3 periods
2. Diffusion & Osmosis Advanced Inquiry Lab	Cell Transport	4 – Open	5 periods
3. Mystery of the Seven Deaths Case Study	Cellular Respiration	3 – Guided	3 periods
4. Cellular Respiration Advanced Inquiry Lab	Cellular Respiration	4 – Open	4 periods
5. Rate of Transpiration Advanced Inquiry Lab	Plant Structure & Function	4 – Open	4 periods

These activities differ from a traditional approach where I would typically lecture about a topic and engage the students in a large group discussion because they had the opportunity to actively practice and apply what they were learning through their own exploration of ideas. These activities prompted students to develop hypotheses and ideas, execute a plan to address challenges, and problem-solve in order to explain scientific principles and phenomenon. In their lab groups, they experienced the collaborative nature of science as they communicated with other students and myself to discuss and defend their individual ideas and thought processes.

Data Sources and Data Collection

To guide my research, I collected a variety of data sources to document student engagement, comprehension of scientific concepts, and attitudes towards science/student confidence in their ability to do science. Some of these data included my own personal journal/reflections after each inquiry activity, field notes during the classroom observations, student exit slips, student grades, student self-assessment survey, and student interviews. I collected the data throughout ten weeks in my 7th period AP Biology classroom.

- *Personal Journals/Reflections*: I kept a journal and made entries at the conclusion of each period on the days students were working on the inquiry activity. I would usually journal and reflect for 10-15 minutes during my 8th period office duty or after school on Tuesdays. I took this time to reflect on my teaching and jot down what was happening in my classroom. As Falk and Blumenreich (2005) explain journaling can be a valuable tool in the research process because it can help you document and remember significant events more vividly. Keeping this in mind, in my entries I included things like what I thought worked well for the day, what went wrong, what didn't play out as I thought it would, how the students were responding to the inquiry, how I was responding, what I found frustrating and what frustrations I observed kids facing. I found journaling as a data source to be a valuable tool since it allowed me to track my thoughts, feelings, and reflect upon my instructional strategies.
- *Exit Slip Questionnaires*: Students completed an exit slip questionnaire in-class at the end of each inquiry activity. The exit slips served as a useful tool because they allowed me to obtain detailed feedback in a quick and organized manner throughout the course of the study from all participants regarding their experiences with inquiry. "Surveys or questionnaires are appropriate tools for obtaining information when you want to consult a lot of people" (Falk & Blumenreich, 2005, p. 100). The exit slip consisted of seven questions, three open-ended and four scored on a Likert scale ranging from (4, Fully agree, to 1, Fully disagree). The questions asked students to assess their understanding of scientific content covered in the inquiry activity and reflect upon on what they liked and what they didn't during the learning episode. For example, one of the

open-ended questions asks students "How well did you understand the activity or lesson that we did in class today? And another one on the Likert scale asks students to rate their understanding in comparison to a traditional lecture *"I am more likely to understand and remember material when I do this type of activity versus a traditional lecture"* (4, Fully agree, to 1, Fully disagree). In analyzing the exit slips, I hope to gain valuable insight about my students' understanding of scientific content and their feelings and attitudes towards the inquiry experience. I used the exit slips as a type of formative assessment and also reflected and journaled about my own reactions to the exit slips after I collected them. A sample of the exit slip used during the research study is attached as Appendix C.

- *Field Notes/Classroom Observations*: I conducted structured observations and took field notes in my classroom every time my students worked on an inquiry activity. As a data collection-strategy, I felt that by observing what was happening in my room and what my students were doing during the inquiry activities it would help me gain a better understanding of the effectiveness of inquiry as an instructional strategy. In addition, by taking a step back and recording what I saw I was better able to document things from an observer's perspective rather than as an active participant of the lesson. "Looking back on those written notes and elaborating on them can provide a bridge between what you are experiencing in the classroom and how you translate the experience into larger meaning" (Shagoury & Power, 2012, p.92) I used an observation form with a check-list of topics to help keep my observation focused on specific student behaviors pertaining to their level of engagement with the activity. In addition to the checklist, I also used the notes section to jot down any significant observations and make sketches of each group to document the student interactions. I observed approximately 15 minutes during each period while the students worked on their inquiry activity. I attempted to observe the behaviors of each student in the class at least once during the observation period. I found the data collection to be easier when I focused on each cooperative lab group for a few minutes, than when I looked at the entire class as a whole. As a result, I completed one observation form for each group to document each group's behavior. The observation form that I used to jot down my field notes is attached in Appendix D.

- *Student Grades:* Students' overall averages in the course were recorded at the beginning of the research project and at the completion. Cumulative grades reflect assessments such as quizzes, lab reports, case study write-ups, and unit tests on content covered through the use of inquiry activities. Grades will be analyzed to determine the level of student academic achievement and student comprehension.
- *Student Science Skills Self-Assessment Survey:* All students in the course were asked to complete a science skills self-assessment survey at the end of the ten-week research project. Similarly to the exit slips, I felt a survey would be useful at pooling results from all study participants regarding their experiences with inquiry. However, the survey was given at the end of the study as one summative evaluation rating students' overall experience with inquiry throughout the ten week period, rather than at the end of individual activities. Shagoury and Power (2012) suggest that surveys can be useful if you want to obtain feedback regarding a specific instructional strategy from a given group. In this case, I wanted to obtain information regarding inquiry as an instructional approach from my students. The survey was administered on-line through Survey Monkey and

the students had to rate their overall experience with inquiry-based activities on a Likert scale. The survey was composed of ten questions that included topics related to their current interest level in science, confidence in their ability to complete scientific activities, how engaged they felt during inquiry activities, and whether inquiry enhanced their understanding of scientific concepts. The survey that I used for my research study is attached in Appendix E.

- *Student Interviews:* After students completed the five inquiry activities for my study, I selected a sample of 10 students from the class to interview. I selected the students randomly based on their own willingness to volunteer for the interview. I conducted semi-structured interviews during the tenth week of my research project. The semi-structured nature of the interviews provided me with an opportunity to develop a deeper understanding of student responses because it gave me the flexibility to explore student responses by asking them to elaborate on their answers. Falk and Blumenreich (2005) describe interviews as a time-consuming yet valuable data source if, as the researcher, you are looking to gain a deep understanding of the interviewees' perspective. The semi-structured interviews were held individually with each student for 15-25 minutes before and after school. I recorded the information by taking notes in my notebook. The students were asked open-ended questions pertaining to their experiences with inquiry-based activities and how it impacted them as learners. With the interviews, I was looking to assess student attitudes and whether they felt inquiry was a valuable learning experience for them. Some of the interview questions asked were: Do you think that learning science through inquiry is effective? Why or Why not? How would you say your participation with inquiry activities have impacted your understanding of scientific concepts and your overall academic achievement in science? For a complete list of the interview questions asked to study participants please see Appendix F.

Findings

Through analysis and interpretation of data collected during my research study I documented the effect of using inquiry based activities, such as labs and case studies, on my students' engagement, understanding of scientific content, attitudes towards science, and self-view in their confidence to perform scientific tasks. I organized my research findings around the following a priori themes: engagement, achievement, and confidence in relationship to inquiry.

Student Engagement

In reviewing my journal entries and field notes/classroom observation forms I found that when students were involved in an inquiry activity, whether trying to figure out a case study or designing their own lab investigation, their level of engagement was generally high. During the five inquiry activities, I recorded qualitative data on specific student behaviors such as body language (attentive, pensive, sitting up, daydreaming), staying on task during the activity, intellectual investment (formulating questions to investigate, coming up with a hypothesis and procedure, manipulating lab equipment and tools), and actively communicating with other students to document the students' level of engagement with each activity. My field notes document students bouncing ideas off of each other, brainstorming collaboratively to solve a problem, and trying to develop adequate questions or hypotheses to test and study. In addition, students were listening to each other, asking questions, participating in the activity, staying on task, and contributing to key ideas by supporting their point of view or explaining their thought process or decision regarding the investigative procedure to other students. All of which serve as evidence to support a high level of engagement during the inquiry episode.

Furthermore, students were found to display positive body language indicative of engagement when participating in the inquiry-based activities. I recorded that most of the students were smiling, establishing eye-contact with their fellow lab partners, sitting-up at their lab benches, gathering required materials, and involved in setting-up apparatus for the lab investigation or actively collecting and recording data. I also noted that a few students (2-3 students, depending on the specific inquiry activity) appeared off-task and disengaged during the three lab inquiry activities (the same 2-3 students each time), but not during the two case studies.

In the science skills self-assessment survey, students were asked a series of self-reflection questions as a means to measure the level of engagement and participation from the student perspective during inquiry activities. The findings from the responses to the survey reveal that 68.18% (15/22) of the students felt engaged most of the time or very often, 27.7% (6/22) felt engaged often, and 4.55% (1/22) never felt engaged during the inquiry episode. The results are summarized in Table 1.

Table 1: Student Engagement

A measure of engagement as reported on questions from student self-assessment survey (n=22).

Survey Question	Most of the Time	Very Often	Often	Somewhat Often	Almost Never	Never
How would you rate your level of engagement when you performed inquiry activities?	5 22.73%	10 45.5%	6 27.7%	0 0%	0 0%	1 4.55%
I actively participated with other group members during the inquiry activity to formulate hypotheses, design procedures, choose adequate materials, identify variables, discuss accuracy of data, and draw conclusions.	8 36.6 %	9 40.91%	4 18.18%	1 4.55%	0 0%	0 0%
I held myself accountable for high quality work during inquiry activities.	11 50.0%	7 31.82%	4 18.18%	0 0%	0 0%	0 0%
I provided ideas that contributed to overall success of the inquiry activity. Without my help, our results would have not been as good.	7 31.82%	4 18.18%	7 31.82%	3 13.64%	0 0%	1 4.55%

During the student interviews, students were asked to explain if they felt participation with inquiry-based activities was a valuable experience for them. All students interviewed reported that inquiry was a valuable experience for them and that it helped them learn the material better. In addition, many of their responses to this question referenced their level of engagement and investment during the inquiry activity and how this seemed to enhance their overall interest in the learning episode. One student reported,

> "I feel this was a very valuable experience for me, especially the case studies. Sometimes, I ask myself: How is this relevant? Through inquiry I was able to see that content does matter and has a real life application. Inquiry made learning topics like *Cellular Respiration* so much more interesting. My partner and I were eager to figure out what had killed the patients and we didn't want to stop until we solved the mystery."

Another student made the following statement:

> "In the past, science labs were very scripted telling us exactly what to do. I have never gotten this type of experience in other classes and I really enjoy the flexibility and freedom we get to create our own design and test our own ideas. It

keeps me more interested and active since we have to figure things out as we go along and we don't know exactly what is going to happen or where we are going to end up."

Student Achievement and Understanding

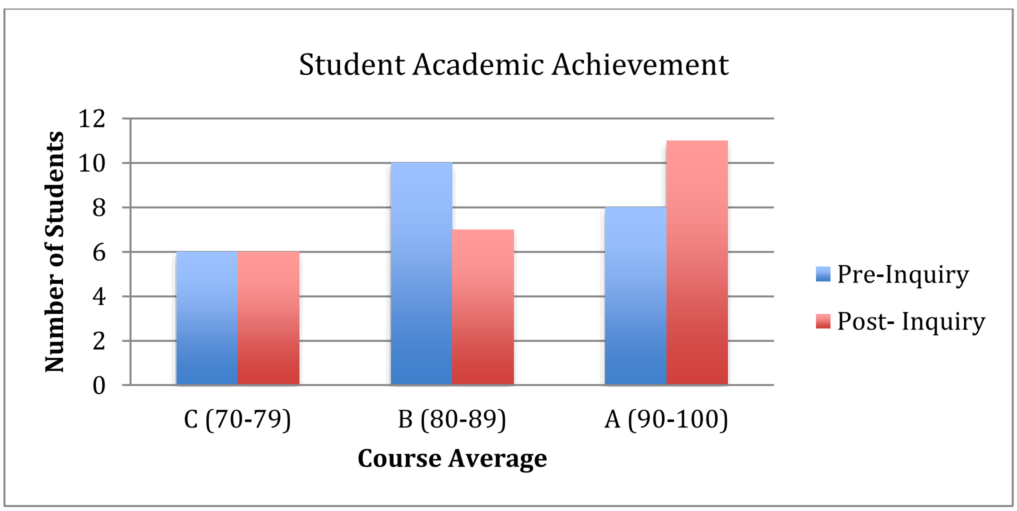
Achievement and understanding of scientific information was measured quantitatively by looking at the students' overall academic average in the course at the beginning of the research study and comparing it to their overall academic average after participation in the inquiry-based activities. Eleven (45.8%) students demonstrated improvement in their academic performance showing a slight increase in their overall average grade after participation in the study. However, the research findings do not support a significant change in student grades or academic achievement after participating with inquiry-based activities. Table 2 summarizes the findings pertaining to each individual student's average pre- and post- inquiry. Figure 2 summarizes the overall results of the class performance and achievement pre- and post- inquiry.

Table 2: Student Averages (n= 24)

Student Number	Pre-Inquiry Course Average	Post-Inquiry Course Average
1	73 (C)	73 (C)
2	87 (B)	89 (B+)
3	93 (A)	91 (A-)
4	90 (A-)	91 (A-)
5	92 (A-)	92 (A-)
6	84 (B)	79 (C+)
7	96 (A)	95 (A)
8	84 (B)	81 (B-)
9	81 (B-)	84 (B)
10	79 (C+)	81 (B-)
11	90 (A-)	90 (A-)

12	97 (A)	98 (A)
13	88 (B+)	87 (B)
14	76 (C)	75 (C)
15	95 (A)	95 (A)
16	79 (C+)	76 (C)
17	88 (B+)	90 (A-)
18	86 (B)	92 (A-)
19	79 (C+)	73 (C)
20	82 (B-)	83 (B)
21	83 (B)	81 (B-)
22	92 (A-)	96 (A)
23	89 (B+)	90 (A-)
24	75 (C)	77 (C)

Figure 2: Summary of Grade Distribution Pre- and Post- Inquiry (n = 24)



The findings from the qualitative data such as my journals and field notes, student exit slips, and student interviews, did however support a positive correlation between the use of inquiry activities and an increased level of understanding. In my journal entries and field notes, I recorded that although some students appeared to be struggling initially with understanding content, by collaborating with their team members they all seem to be figuring things out at their own pace. Frustration is high among some students in the class, but most are willing and attempting to reach a deeper level of understanding on their own by asking questions and listening to the explanations from their peers. Furthermore, when probed by me for an informal check for understanding many students are able to explain key theoretical concepts correctly.

The quantitative findings from the exit slips reveal that 71.7% (17/24) students fully agree or partially agree with the idea that they are more likely to understand and remember material through inquiry versus a traditional lecture. In addition, 90% (22/24) students fully agree or partially agree that they learned a lot during the inquiry activities. These findings are summarized in Table 3.

Table 3: Data on Understanding from exit slips, students' general evaluation of each inquiry activity (n=24).

I learned a lot during this activity	**Fully Agree**	**Partially Agree**	**Partially Disagree**	**Fully Disagree**
Inquiry Activity 1	5	15	4	0
Inquiry Activity 2	13	9	2	0
Inquiry Activity 3	14	7	3	0
Inquiry Activity 4	11	10	3	0
Inquiry Activity 5	9	15	0	0
Average	**10.4 (43.3%)**	**11.2 (46.7%)**	**2.4 (10%)**	**0 (0%)**
I am more likely to understand and remember material when I do this type of activity versus a traditional lecture				
Inquiry Activity 1	5	8	8	3
Inquiry Activity 2	3	14	7	0
Inquiry Activity 3	11	5	7	1
Inquiry Activity 4	9	11	4	0
Inquiry Activity 5	7	13	4	0
Average	**7 (29.2%)**	**10.2 (42.5%)**	**6 (25%)**	**.8 (3.3%)**

In reviewing the open-ended questions in the exit slips most students reported a high level of understanding at the completion of each inquiry activity. Typical comments regarding understanding included:

"At first, I had a difficult time understanding what was going on, but once I

> worked through it I understood it really well."
>
> "Seeing things first hand always helps me understand topics better, lecturing tends to lose my attention."
>
> "All the experimental factors of the lab helped me get a real-life understanding of how transpiration works. Listening to the lectures only goes so far and I enjoy being able to see and do things in a more tangible form."

Some students felt more apprehensive and negative towards their inquiry experience. Most of the negative comments pertained to the level of frustration, faulty data or results that didn't agree with what they expected to see, and the heavy workload associated with the inquiry labs. Some students reported:

> "Honestly, this lab was too much work and there were too many possibilities for failure that it wasn't worth it."
>
> "This lab was fun to set up and try to get to work, although it was frustrating. I really liked the hands-on aspect, but it was so time consuming. I feel like it would've paid off if our data was actually correct in the end."
>
> "I loved the hands-on approach and working with the live crickets. It really helped me understand how cellular respiration works in living organisms. However, I hated the set-up because it was so time consuming and tricky."

The responses during the student interviews mirrored those of the exit slips. When students were asked, how would you say your participation with inquiry activities have impacted your understanding of scientific concepts and overall academic achievement in science? Students generally replied that inquiry provided them with an opportunity to deepen their understanding and test their own knowledge. One student replied, "you really need to know and understand the material well in order to design the labs and figure out the cases." She stated that the inquiry activities served as a checking point for her to see if she really understood concepts or still needed additional help.

Overall, positive comments during the student interviews about the inquiry activities focused on how relevant inquiry made the material and how as a result students were now able to relate and apply concepts to something in real life. In addition, students stated that the inquiry activities helped them understand material better by allowing them to manipulate information first hand in a way that made sense for them. During the interviews, one student shared with me that she came from a family of gardeners and that every year she planted flowerbeds with her mom. As a result of the transpiration inquiry lab, she said she was finally able to really understand why some plants grow easily at her home in NJ while they die in their vacation home in the Poconos. Furthermore, she explained to me how excited and confident she felt when she went home and shared this newfound knowledge and understandings with her family.

Another finding from this study was about the positive relationship between student collaboration or group work and the understanding of knowledge. In both the exit slips and interviews, students repeatedly reported that their understanding of scientific concepts was enhanced because of the collaborative nature of the inquiry activities. They made comments stating that being able to discuss things and figure things out together made it easier for them to understand content, problem-solve, and make sense of the data they had collected. Students stated that they really enjoyed working with their classmates and the teamwork aspect of the inquiry.

Student Confidence and Attitudes

To determine student perception of confidence in their ability to perform scientific tasks students were asked to complete a self-efficacy survey at the completion of the study. Findings show that 72.7% (16/22) students reported being extremely confident or very confident in their ability to perform scientific tasks, 77.7% (17/22) feel extremely confident or very confident in their ability to explain or write about biology, and 91% (20/22) feel extremely confident or very confident in their ability to use a scientific approach to solve problems. These findings are summarized in Table 4.

Table 4: Student Confidence

A measure of student confidence as reported on questions from student self-assessment survey (n=22).

Survey Question	Extremely Confident	Very Confident	Fairly Confident	Not Confident
How would you rate your confidence in your ability to perform scientific tasks, such as designing your own lab procedure to investigate a scientific concept?	8 36.36%	8 36.36%	6 27.27%	0 0%
How would you rate your confidence in explaining and writing about biological ideas or concepts?	6 27.7%	11 50.0%	4 18.18%	1 4.55%
How would you rate your confidence in using a scientific approach to solve problems?	10 45.45%	10 45.45%	2 9.09%	0 0%

Student attitudes towards science were assessed based on students' responses to questions in the exits slips, during student interviews by asking students to elaborate on their likes or dislikes with inquiry and how this impacted their overall interest in science, and also in the self-assessment survey by recording student interest in science at the completion of the study. Findings reveal that 90% (22/24) of students fully agree or partially agree that they enjoyed completing inquiry activities and 85.8% (20/24) of students fully agree or partially agree that they prefer doing inquiry activities instead of a traditional lecture. These results are summarized in Table 5.

Table 5: Data on Attitude towards science from exit slips, students' general evaluation of each inquiry activity (n=24).

I prefer this type of activity to a lecture	**Fully Agree**	**Partially Agree**	**Partially Disagree**	**Fully Disagree**
Inquiry Activity 1	5	13	4	2
Inquiry Activity 2	11	8	4	1
Inquiry Activity 3	11	10	3	0
Inquiry Activity 4	13	8	3	0
Inquiry Activity 5	15	9	0	0
Average	**11 (45.8%)**	**9.6 (40%)**	**2.8 (11.6%)**	**0.6 (2.5%)**

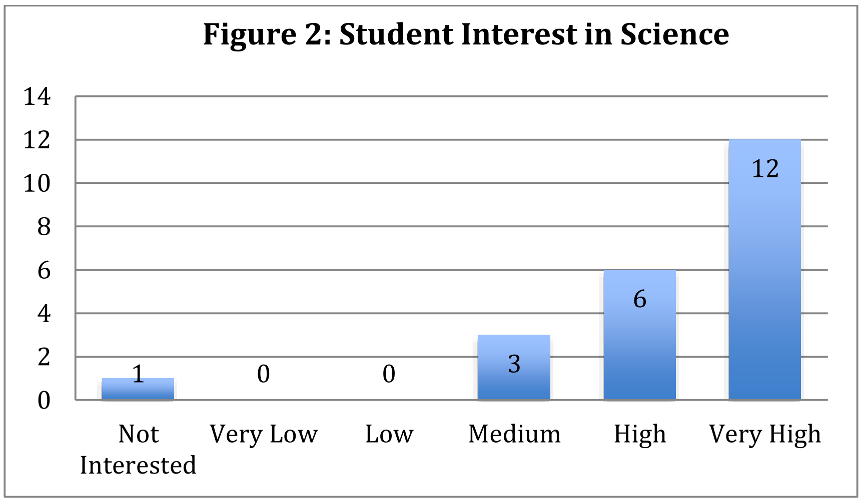
I enjoyed doing this activity	**Fully Agree**	**Partially Agree**	**Partially Disagree**	**Fully Disagree**
Inquiry Activity 1	6	13	4	1
Inquiry Activity 2	13	9	2	0
Inquiry Activity 3	15	9	0	0
Inquiry Activity 4	14	7	3	0
Inquiry Activity 5	16	7	1	0
Average	**12.8 (53.3%)**	**9 (37.5%)**	**2.4 (10%)**	**0.2 (.8%)**

In addition, students that were interviewed further elaborated and generally concurred that they really enjoyed collaborating with other students, the creativity aspect of the inquiry, the hands-on approach, the practical experience in a lab setting, and the self-guided application of concepts. All interviewed students (n = 10) reported an increased interest in science due to exposure with inquiry. One student stated, “as a result of designing my own labs and from the enjoyment I’ve gotten out of them, I’m now considering going into biochemistry next year. I’ve discovered some of my strengths and weaknesses, and I realized that I’m really good at this and would like to pursue this line of work in my future.”

When asked about their dislikes with inquiry, students were in agreement that the biggest downfall was the time and effort it took to complete the activities. These dislikes are consistent with previous findings reported by Armstrong et al. (2009). Common complaints among my students included a lack of time or feeling rushed for time, the fact that they didn’t always know what to do and this made them feel uncomfortable and frustrated, disappointment in erroneous data when it didn’t support their ideas or hypotheses, and the workload associated with inquiry, especially during the lab investigations. However, even with all the complaints surrounding student experiences with inquiry the study findings indicate a positive correlation between an increased interest in science and inquiry. In the self-assessment survey, students were asked: How would you rate your interest in science right now? The majority of the students, 81.82% (18/22), reported a very high or high interest in science at the completion of the study. These findings are summarized in Figure 3.

Figure 3: Summary of Interest in Science

A measure of student interest as reported on question 1 from student self-assessment survey (n=22).



Discussion

My personal goal for trying to infuse inquiry activities into my classroom is to get my students to develop scientific skills through application of knowledge and information in a way that is more meaningful, engaging, and enjoyable for them. As previously discussed, these educational beliefs are deeply grounded on the learning theory of constructivism. "Constructivism says that people construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences" (Thirteen Ed Online, 2004). This learning theory emphasizes the learner as an active participant and the idea that knowledge is constructed through experience. The American Association for the Advancement of Science (AAAS) in *Vision and Change in Undergraduate Biology Education: A Call to Action* identify constructivism as the primary learning theory fundamental to the use of inquiry teaching methods in the classroom (AAAS, 2011).

This research study and the infusion of inquiry has been an extension of what I started playing with in my classroom last year and have been trying to implement on a more frequent basis ever since. I have been working towards building a constructivist classroom through the use of inquiry. However, I was unsure if inquiry would actually work or if it would be well received by the students. I also wondered what type of impact, if any, it would have on my students' learning and their overall experience with science in my class. And lastly, what type of impact would inquiry activities have on me as their teacher?

Impact on Engagement

The findings of my study regarding student engagement as a result of participation with inquiry are consistent with that of prior researchers (Murray & Summerlee, 2010; Baptista et al., 2012) and suggest a positive correlation between doing inquiry activities and feeling engaged with the learning episode. In their study, Murray and Summerlee (2010) reported that students who participated in an inquiry-based learning seminar had higher levels of engagement when compared to their peers in the control group who did not participate in the inquiry-based seminar. Similarly, although a control group was not used, this study found that generally when students were involved with inquiry they experienced a high level of engagement. These results can be attributed to the nature of the inquiry activities used because they required students to take an active role in their own learning making it difficult for them to sit back and obtain information passively. In line with constructivism, the activities in the study prompted students to ask and develop their own questions, lab procedures, explore possible solutions to problems, analyze and evaluate data, and make meaning of their findings. “Constructivism is a student centered learning theory, which assumes that learning will take place when students are actively engaging with the topic and constructing their own knowledge bases” (Hartle et. al, 2012).

Another explanation for increased student engagement during the inquiry activities is that students were able to connect content to a real-life application. During the interviews and in their exit slips, students mentioned that when they realized the case studies were based on real stories they became more interested and motivated to try to figure them out and propose reasonable explanations. It appears that the relevance of the content made the students feel more engaged. “By grounding activities in an authentic, real-world context, constructivism stimulates and engages students” (Thirteen Ed Online, 2004). These findings are consistent with those of Baptista et al., (2012) which suggested that when students are presented with authentic learning opportunities their interest levels peaked.

In addition to authenticity, I also feel that the autonomy and openness provided through the inquiry activities, especially in the labs, played a big role in keeping the students engaged and actively involved in the lesson. Students were provided with an opportunity do real scientific inquiry by posing their own questions and proposing an individualized investigative design. They were given choice and flexibility in their approach and use of materials. Once again, during interviews and exit slips, multiple students expressed appreciation for the flexibility to choose topics they had an interest in versus being told exactly what to do. “A key recommendation is that biology courses and curricula must engage students in how scientific inquiry is conducted, including evaluating and interpreting scientific explanations of the natural world” (AAAS, 2011).

Impact on Achievement and Understanding

According to the National Science Education Standards, "inquiry is central to science learning" and "learning science is something students do, not something that is done for them" (NRC, 2000). This study was framed around these central ideas and invited students to engage with content by designing their own lab investigations or working through a case study in order to enhance their understanding of science and ultimately increase their academic achievement in science. However, the findings regarding academic achievement as measured by student grades do not support a significant change in achievement after participation with inquiry-based activities. It is possible that the methods used in this study could promote long-term benefits regarding understanding of science and that the data collection period was too brief to demonstrate any significant gains in academic achievement. This is an area that warrants further research. My study findings pertaining to achievement are inconsistent with those of previous studies (Murray & Summerlee, 2010) (Doppelt et. al, 2008) and (Armstrong et. al, 2009), which suggest an increase in academic achievement as a result of inquiry. This can be attributed to a number of variables independent of the exposure to inquiry, such as differences in the type and difficulty level of the material covered within the curriculum as the study progressed, different types of assessments also at varying degrees of difficulty, student effort, homework completion, and emotional state of students during summative assessments. Some students reported that although they felt the inquiry activities really enhanced their understanding of material, they didn't always feel as though this translated into a higher grade on a test because they felt anxious during the tests or made silly errors which cost them points or they simply experienced difficulty answering the long free-response AP style questions typical of our summative assessments.

Although the results pertaining to academic achievement do not show significant grade point average gains, other study findings do support the notion that exposure to inquiry will lead to greater student understanding of scientific ideas and concepts. This can be attributed to factors such as the use of cooperative group work during the inquiry-based activities or the active manipulation of content on the part of the student that is required during inquiry, both of which can lead to deeper levels of understanding. Many students reported that by working with other students and helping each other figure things out they were better able to understand key concepts at hand. "Cooperative learning activities provide a mechanism for students to develop a feeling of community in the classroom and relationships are viewed as a positive force in learning that promote achievement and understanding through commitment and mutual goals (Kreke et. al, 1998). Study findings suggest that through inquiry activities, students were able to reach deeper levels of understanding because they were able to work with others to problem-solve, explain, plan, execute, communicate, elaborate, and justify their reasoning within their groups and as a result learn with and from each other. These findings are consistent with existing literature regarding the impact of inquiry in science instruction (Minner et al, 2010). In their analysis of 138 research studies, Minner et al (2010) found a positive correlation across the literature suggesting that inquiry based teaching strategies are more likely to increase understanding of concepts.

Impact on Self-confidence and Attitudes

This study documented that after participation with inquiry activities students reported high levels of confidence in their ability to perform scientific tasks, in their ability to explain and write about biological ideas, and in their ability to use a scientific approach to solve problems. This high level of confidence as reported from the students' perspective in their scientific skills and abilities could be attributed to the repeated exposure, experience, and comfort that students eventually acquired as they got used to participating in inquiry settings. Students were required to practice these types of scientific skills in every single inquiry activity, so it makes sense that after repeated exposure throughout a ten week period to these skill sets they would feel more confident and as a result rate themselves highly on the self-efficacy survey.

In addition, study findings also suggest a positive correlation between participation with inquiry activities and positive student attitudes towards science. Osborne et al. (2003) suggest that students exhibit positive behaviors towards science when:

- They accept scientific inquiry as a way of thought
- Adopt scientific attitudes
- Enjoy the science learning experiences
- Develop interest in science and science-related activities
- Develop an interest in pursuing a career in science or science related work.

As expressed through their responses in the exit slip questionnaires and in the student survey, students generally felt optimistic about the inquiry activities and expressed high levels of joyfulness during the activities suggesting they would like to do more inquiry type activities and prefer them to traditional lectures. Data tracking student attitudes towards science, as determined by exit slip questions of enjoyment and preference, show a positive change in student attitudes from the beginning of the study (***Inquiry Activity #1*** = 6/24 students fully agree they enjoyed this activity; 5/24 prefer inquiry to lecture) to the completion of the study (***Inquiry Activity #5*** = 16/24 students fully agree with enjoyment; 15/24 students prefer inquiry to lecture). These differences can be attributed to development of comfort, better understanding of their role, and knowing what to expect with inquiry. In the article "*Inquiry Based Science: What does it look like?" (*Connect Magazine, 1995), teachers and administrators report that through participation in inquiry science, children learn to:

- View themselves as scientists in the process of learning.
  - ⇒ They look forward to doing science.
  - ⇒ They seek to collaborate and work cooperatively with their peers.
  - ⇒ They are confident in doing science; they demonstrate a willingness to modify ideas, take risks, and display healthy skepticism.
- Accept an invitation to learn and readily engage in the exploration process.
  - ⇒ They take the opportunity and the time to "try out" their own ideas.

In accordance with this article, study findings show that students generally enjoyed participating in the inquiry activities and as a result looked forward to completing the activities and doing science. My field notes document students collaborating with each other to explore ideas, question concepts, develop hypotheses, and modify original hypotheses based on the data they collected and analyzed, which speaks to their confidence in doing science. Students typically began their inquiry experience by developing a question followed by a hands-on approach to investigate possible solutions or explanations to scientific concepts. In addition, I recorded students willingly partaking in the inquiry process by designing unique procedures, selecting appropriate materials, and setting up laboratory apparatus with their peers in order to test out their ideas. This is in line with thinking like a scientist and accepting an invitation to learn and readily engage in the exploration process.

In addition, at the completion of the study students also expressed a very high interest in science. These positive attitudes could be attributed to students feeling a sense of accomplishment from being active participants in their own learning. Furthermore, being able to see relevance between science content and the real life would also reinforce interest and make science more fun, engaging, and relatable for the students. The study findings pertaining to attitudes are consistent with those presented by Osborne et al. (2003), which suggest that when science curricula provides a more hands-on experience it results in positive attitudes towards school science.

Impact on Me

Throughout this journey, I have acquired a deeper level of understanding about my own personal views and beliefs regarding education. I think that science education, and education in general, should be an enjoyable experience for students and that it should promote hands-on exploration, creative thinking, and problem-solving skills. For me education is about the process and not about the end-result. I have discovered that one of my biggest goals as a science educator is to spark interest and curiosity in science. I want my students to get excited about science and gain an appreciation of the complex interactions between science and society and how these affect them and form part of their everyday lives.

> "These are exciting times for biologists, with changes occurring in all areas of the life sciences, from breakthroughs in genomics and neuroscience to a deeper understanding of the effects of global climate change on Earth's ecosystems. And yet, many of these new areas of biology, and the skills needed to understand and engage effectively in them, typically do not appear in science classrooms and textbooks until many years after their inception, leaving undergraduate biology education lagging behind these exciting scientific advances." (AAAS, 2011)

Through reflection I have thought about how my ideas and beliefs shape my actions and teaching practices. I continuously re-evaluate and question what I am doing in an attempt to make science more accessible, engaging, and relevant for my students. It is my hope that through the use of inquiry-based instruction I become better at meeting my goal. My research findings suggest that this is the case for engagement, understanding, and science interest, but not for student grades.

In addition in shifting away from pushing content through lecture and moving more towards a constructivist inquiry-based classroom, I have learned to give up control and share it with my students. It has been an eye-opening and extremely rewarding experience to see that even when I'm not the one distributing the information and leading the discussion the students are still able to stay on task (perhaps even more so than during lectures), appear to enjoy what they are doing, and are acquiring the essential content and knowledge from the lesson. I was fearful and skeptical that this would not be the case and that my students would not be able to handle inquiry, but my results show otherwise.

My role as a teacher during inquiry-based instruction has also shifted, but it is still very active. I guide and facilitate the laboratory investigations or case study investigations and provide students with continuous formative feedback without revealing results (which sometimes during labs are also unknown to me). I have found this experience to be extremely refreshing and the student interest I have witnessed makes the workload on my end, especially with the set-up of inquiry labs, worthwhile. "Constructivism posits that the teacher's role is to help their students to actively construct new understanding for themselves" (Hartle et al., 2012).

Obstacles

Throughout the course of the research project I encountered a few obstacles along the way, which included initial student resistance to inquiry, time, and juggling additional workload on my end to make the inquiry happen. When I first introduced inquiry activities in the class my students were a bit hesitant and uncomfortable with the situation. Their lack of prior exposure and experience with inquiry activities made them feel uncomfortable and I think this is one of the reasons they didn't like inquiry too much at first. During the initial inquiry labs, some students made comments like "can't you just tell us how to set-up or give us a hypothesis to test." Initially, it took a lot of reassurance and support on my end. I had to continuously emphasize to students that it was "ok" for them to not know all the answers and that the important thing was the process and not the end result. This concept took a little bit of buy-in on their end, but by the end of the study I think most students came to realize that they were in a safe environment where they could take risks and that they could count on their peers and myself to help them overcome challenges and figure things out.

Another major obstacle, and I'm not sure I have discovered any answers for this one or have overcome it, was lack of time. With only 43-minute periods to set-up and run an inquiry lab, juggling materials, apparatus, and data collection required of most investigations became very difficult and tricky for the students. I tried to get around the time issue by getting students to break-up their lab into multiple parts they could carry out over the course of various days. However, even like this, students usually felt rushed for time and splitting the investigation made continuity of data difficult to obtain. "Fifteen years ago, the National Education Commission on Time and Learning explained the American school calendar of 180 six-hour days stands as the design flaw of our education system" (Farbman, 2010). Proponents of an extended school day argue that under our current school calendar it is very difficult to provide enough time for students to experience a variety of teaching methods. A teacher survey, Massachusetts Teaching Learning and Leading Survey (MassTeLLS), conducted by Masachussetts 2020 of more than 40,000 teachers across the state found "over 60% of teachers report there is insufficient time to complete the curriculum, meet the needs of all students, or collaborate with their colleagues about instructional practices" (MassTeLLS, 2009). In Massachusetts, they have found that expanded learning time (ELT) in schools is benefiting students with more teachers reporting that their students are learning more and their teaching has changed because of an increased opportunity to use multiple teaching methods (MassTeLLS, 2009). Farbman (2009) reports that students in schools with ELT outperform students in schools with traditional hours, suggesting a positive correlation between learning time and performance (Farbman D., 2009).

Lastly, one final obstacle I have had to overcome and am still learning to manage is the workload associated with converting my existing labs and activities into more open-ended and student centered inquiry activities. In redesigning labs and activities, I have taken into account the five essential responsibilities of learners conducting inquiry-based labs as presented by the NRC in *Inquiry and the National Science Education Standards: a Guide for Teaching and Learning* (NRC, 2000):

1. Engaging in scientifically oriented questions
2. Giving priority to evidence in responding to questions
3. Formulating explanations from evidence
4. Connecting explanations to scientific knowledge
5. Communicating and justifying explanations

This transition to a more student-centered approach has required a substantial amount of investment and dedication on my part. I believe in this change and feel it is worth the investment, but I can see why some teachers may be initially resistant to it. I have a significant course load teaching, prepping and setting up labs for 4 different courses in addition to the day-to-day responsibilities of teaching and like so many others very little free time. Transitioning the labs from the traditional "cookbook" type to open-inquiry requires a wider variety of materials and equipment for students to select from to meet the needs of their specific designs. Due to this, the teacher preparation required to run inquiry labs is greater than with traditional labs.

Limitations

This study has a few limitations. The study was conducted in just one type of science course (biology) with a relatively small sample size of 24 students. In addition, only one teacher participated and it was just conducted in one high school. Due to this, the results may not be representative of the effect of inquiry in all science classrooms and cannot be generalized. Furthermore, due to time constraints only five inquiry activities were performed, which once again may not be sufficient to document the effect of inquiry on students. In addition, because the study did not have a control group and all students were involved with inquiry it is difficult to compare its effectiveness to a more traditional approach.

Emerging Questions

I have been able to gain valuable insight on the effect of inquiry in my classroom and how it has impacted my students. However, I still have additional questions as I move forward and plan to continue implementing an inquiry-based instructional approach on a larger scale. For this study, I focused on the infusion of inquiry at the AP level with senior students. I want to bring this instructional approach down to the underclassmen in the other courses that I teach. Could the use of inquiry be a successful and effective instructional strategy at making science more relevant, enjoyable, and interesting with lower level students, such as CP biology or in-class support biology? Am I better equipped to foresee student challenges and anticipate misconceptions and frustrations that may arise as a result of inquiry? Is the "time" piece a significant factor or impediment to conducting inquiry-based instruction at my school? Do other schools that have extended hours or block scheduling experience more success with the implementation of innovative teaching strategies, such as inquiry? Will participation in this study have any long-term effects on my students? Could an inquiry-based approach to teaching science generate or lead to greater long-term interest in science or science related careers? Can I successfully implement inquiry on a broader scale? Is it sustainable? Realistic? or Will the time investment and effort required to restructure existing curriculum be too much for me to handle and eventually lead to burn-out?

Conclusion

This study explored the effect of inquiry-based instruction on student engagement, understanding, achievement, attitudes towards science, and confidence in student ability to perform scientific tasks. In accordance with the constructivist learning theory, the study highlights the importance of providing students in a science classroom with an authentic opportunity to experience the processes of science allowing them to discover knowledge for themselves. Study findings suggest a positive correlation between the use of inquiry-based instruction and student engagement, student understanding, student confidence in ability to complete scientific tasks and student attitudes towards science. This study did not document significant changes in academic achievement and as a result further research is warranted in this area.

In my opinion, conducting inquiry in biology can be a challenging task, but at the same time feel it can be an extremely rewarding and fun experience for both students and teachers. Based on the research findings inquiry based instruction can improve the quality of science education for students by enhancing their levels of engagement, understanding, and interest in science.   As a result, I feel it is worth the effort and that the benefits of utilizing inquiry based teaching methods far outweigh the challenges. As educators, it is ultimately our responsibility to challenge our students to think critically, get them to make connections, and apply content knowledge in order to promote their higher-order thinking and problem-solving skills. Inquiry can help students gain a deeper appreciation of science and can also help them develop skills necessary to become life-long learners.

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Appendix A: Implementation Plan

Utilizing a student-centered inquiry-based instructional strategy, which focuses on depth of content over breadth of content was effective at increasing my students' interest in science, confidence in their ability to do science, and contributed to an increased level of engagement with content among the students in my class. Based on these findings and the knowledge gained from conducting my study, I feel that this instructional approach has a solid pedagogical foundation and implementing it into other science curricula can enhance the learning experience for students and promote a greater interest in science among students.

As a result, I plan to share my study findings with my science supervisor and request an opportunity to present this information to the other members of my department at one of our science departmental meetings. I know that adopting an inquiry-based approach to teaching science may appeal to some teachers in my department, but they may be unsure of how to implement such strategies and feel a little intimidated by what an inquiry process of instruction entails. I am excited to share my findings and offer my support and newfound insight into using inquiry with colleagues that may be willing to embark on this exciting journey of changing the way we teach science at our high school.

From my experience of working in this district for the last ten years, I also know that a few of my colleagues are very traditional and prefer lecture as their primary means of instruction. It is not my intention to change their approach, but I do hope that by presenting my research and findings regarding students' perspective on interest, engagement, and understanding of science and by sharing my own personal experiences in this process, they may be more willing and open to trying and experimenting with inquiry in their own classrooms.

Adoption of an inquiry-based approach to teaching science can be a complex undertaking. As a result, I have already discussed the possibility of creating a small group or professional learning community with two other biology teachers at my school who are also interested in implementing an inquiry based instructional approach. I have peaked their interest in this topic through informal discussions we have had during lunch in which I have shared a quick overview of the promising aspects of my research project. We are planning on starting our group next September and hope to meet afterschool at least once a month throughout the entire school year. By working together, supporting each other, and collaborating we will be more efficient at modifying and transitioning the current traditional labs we use and familiar activities into open inquiry labs.

I plan to share with my colleagues in our professional learning group the knowledge gained from my experiences with inquiry this year and also the labs and activities that I have already restructured and used for my research study. This will provide us with a foundation and initial database to work from that we could modify together and continue to develop and grow as we become more comfortable and familiar with inquiry. Our focus will be on infusing inquiry activities to enhance our current biology curriculum to make it more engaging and interesting for our students while promoting analysis and critical-thinking skills.

In addition, by having this small group we will have an opportunity to collaborate with one another to modify, improve, and develop more meaningful lessons. In our meetings we will have an opportunity to share ideas, resources, and best practices about what is working in our classrooms and what isn't. This opportunity for continuous dialogue will help us brainstorm and come up with innovative ways of using inquiry to better meet the needs of our students. I am extremely excited and reenergized about the idea of working with other colleagues to continue my research, bounce ideas off of each other, and have an opportunity to learn from one another.

Moving forward, in my AP biology class I will continue to implement inquiry-based activities and gather data to reflect on how students respond to such activities. My study failed to show any significant gains in student grades as a result of participation with inquiry, which for the purposes of my research I described as academic achievement. I do feel that participation in inquiry-activities can enhance student understanding and develop their critical-thinking skills, which can ultimately lead to higher levels of academic achievement within my content area of science. It is possible that the reason I didn't see significant gains in student grades in my study is because the ten-week time period of data collection for my study was too brief to document such changes. Next year, I am interested in tracking longitudinal learning gains in academic achievement in science as a result of using inquiry in the classroom and seeing if my results are any different.

Another major area of change that I have begun to implement and will continue as a result of doing this research study has been the adoption of an inquiry-based instructional approach in the lower level courses that I teach and not just the AP classes. Initially, I was a bit hesitant about trying inquiry in my AP course, but was convinced that my freshman lower level classes, CP biology and honors biology, would lack the maturity, skills, and knowledge base to do inquiry-based activities. Since the completion of this study, I have begun trickling down inquiry labs into my freshman classes and have been extremely pleased with my students' responses to the inquiry process. Similarly to what I documented with the AP students, most of the students were on task and displayed a high level of engagement and interest during the inquiry labs. The students did require a bit more support and teacher direction from my part than the AP students, but overall they did a wonderful job at engaging in scientifically oriented questions. I have not yet done open-inquiry labs (level 4 inquiry) with these classes, but had much success with the guided-inquiry (level 3 inquiry). In the future, I plan to continue incorporating and implementing both levels of inquiry activities on a more frequent basis across all of the courses that I teach and not just at the AP level.

Appendix B: Subjectivity

Conducting this research study has served as a tremendous learning opportunity for me and has changed the way I approach my curriculum and how I want to teach my subject area. The process of change, especially as it pertains to education, is difficult for all parties involved because it represents something different and unknown. I am one of those creatures of habit, which sometimes has a difficult time embracing change and getting on board with doing things differently. When I first embarked on this journey, I was hesitant, skeptical, and a bit apprehensive about my methodology and questioned whether or not inquiry would be an effective instructional strategy. I purposely selected my AP biology course thinking this group of students would be my safest choice to experiment using inquiry-based learning with, since they have a stronger foundation in science than my lower level freshman students.

Changing my instructional approach from a traditional methodology to one that is more student-centered was something I've always wanted to do and started toying with in the past, but at the same time the idea of change was very frightening for me. The lack of formal training on how to teach using inquiry methods made me lack confidence in how to go about to fully implement an inquiry-based teaching approach in my classroom. Furthermore, as a high school student I did not learn science through an inquiry-based approach. The only time I conducted inquiry was in laboratory courses in college and even then, I followed a prescribed traditional laboratory procedure that told me what to do step-by-step. The inquiry I remembered being exposed to was confirmation inquiry (level 1 inquiry) and not very frequently. I was taught science mostly through a traditional didactic content-driven approach that focused on the memorization of large amounts of content knowledge. It was only when I reached my higher-level college science courses and later on in my graduate level work with biology that I first encountered a true open-inquiry approach (level 4 inquiry). This made me question whether I could successfully implement this strategy and this type of inquiry at the high school level where students do not have the science background or expertise I did as science major and as a graduate student.

As a result of this research study, I began to look at the adoption of an inquiry-based instructional approach as an opportunity to embrace a new set of ideas, actions and beliefs. The study provided me with an outlet to do something different, experiment and try new things with my students in the hopes of achieving different results that would make science more engaging, interesting, and relevant for them. This instructional change for me was about taking a risk for the sake of doing things better and improving my craft. In the process, I learned that I am more willing to accept and embrace change and to take risks than I initially gave myself credit for. I have also learned that as difficult and scary as change may appear, it is necessary to reinvent strategies and freshen things up in my classroom so that I may meet the diverse needs of my students and so that I don't become stagnant or bored with the profession. As an educator, just like I tell my students, it is ok to not know all the answers and I can't be afraid to take risks and try things out. I have come to the realization that the worse thing that can happen is I try something and it flops. So what? Now I can use that as a learning opportunity for myself and look at that experience not as a failure, but as a launching point to do things differently the next time around. Only through experimentation and by seeing what works and what doesn't can I continue to grow as a professional and become a better teacher.

Prior to this research study, I struggled and was unsure of how to design and implement inquiry activities with my students. I'm a little embarrassed to admit that I hadn't considered the idea of reading educational journals to see what others were doing in the field regarding inquiry or didn't make the time for it. By doing the literature review and having an opportunity to read and review the work and findings of others I was able to emulate this in my own classroom and learn a great deal about the inquiry process. The study has increased my confidence in my own abilities as a teacher and I now feel quite comfortable and savvy about how to implement an inquiry-based instructional approach in my classroom. This has given me the self-confidence to trickle this approach down into my lower level freshman biology classes as discussed in my implementation plan. In addition, the expertise I have gained in using inquiry methods has given me the confidence to start and guide a learning group with two of my colleagues next year. This is not something that I ever imagined I would do and I don't think I would be here if not for my experiences conducting this research study during the last few months. I guess I have become somewhat of a teacher researcher and I feel excited, invigorated, and empowered by this experience!

<u>Appendix C</u>

<u>Exit Slip</u>

Please answer each question to tell me your thoughts and feelings about today's activity of lesson.

1. How well did you understand the activity or lesson that we did in class today?

2. Are there any parts of the lesson or activity that you are still confused about or concepts that are NOT clear to you?

3. What did you like about this activity? What didn't you like?

I prefer this type of activity to a lecture:

Fully Agree	Partially Agree	Partially Disagree	Fully Disagree

I enjoyed doing this activity:

Fully Agree	Partially Agree	Partially Disagree	Fully Disagree

I learned a lot during this activity:

Fully Agree	Partially Agree	Partially Disagree	Fully Disagree

I am more likely to understand and remember material when I do this type of activity versus a traditional lecture.

Fully Agree	Partially Agree	Partially Disagree	Fully Disagree

Appendix D

Observation Form (page 1)

Date Observed:

Time of Observation:

Inquiry-Activity:

Student Engagement

Student Name	Contributing to group by explaining thought process and defending ideas to other group members	Activity Participation/ Stays on Task	Body Language (attentive, pensive, sitting up, smiling, daydreaming, paying attention)	Intellectual Investment (formulating questions to investigate, formulating hypotheses, designing experiment, manipulating tools, recording results, analyzing data, drawing conclusions, making connections)	Listening to others opinions & effectively communicating with other students.

Observation Form (page 2)

Notes, Questions, Comments:

Appendix E

Science Skills Self-Assessment Survey

Directions: Read the questions and statements below, and answer as best you can. There are no right and wrong answers.

1. How would you rate your interest in science right now?

Very High	High	Medium	Low	Very Low	Not Interested

2. How would you rate your confidence in your ability to perform scientific tasks, such as designing your own lab procedure to investigate a scientific concept?

Extremely Confident	Very Confident	Fairly Confident	Not Confident

3. How would you rate your confidence in explaining and writing about biological ideas or concepts?

Extremely Confident	Very Confident	Fairly Confident	Not Confident

4. How would you rate your confidence in using a scientific approach to solve problems?

Extremely Confident	Very Confident	Fairly Confident	Not Confident

5. How would you rate your level of engagement when you performed inquiry activities?

Felt engaged most of the time	Felt engaged very often	Felt engaged often	Felt somewhat engaged	Almost never felt engaged	Never felt engaged

6. I prefer learning through an inquiry activity rather than through a traditional lecture.

Most of the time	Very often	Often	Somewhat often	Almost never	Never

7. I am more likely to understand and remember material when I do an inquiry activity instead of participating in a lecture/discussion.

Most of the time	Very often	Often	Somewhat often	Almost never	Never

8. I actively participated with other group members during the inquiry activity to formulate hypotheses, design procedures, choose adequate materials, identify variables, discuss accuracy of data, and draw conclusions.

Most of the time	Very often	Often	Somewhat often	Almost never	Never

9. I held myself accountable for high quality work during inquiry activities.

Most of the time	Very often	Often	Somewhat often	Almost never	Never

10. I provided ideas that contributed to overall success of the inquiry activity. Without my help, our results would have not been as good.

Most of the time	Very often	Often	Somewhat often	Almost never	Never

Appendix F

Student Interview Questions

1. What did you like about performing inquiry activities? What did you dislike in comparison to a more traditional approach?

2. How would you say inquiry activities have impacted your overall interest in science?

3. How would you say your participation with inquiry activities have impacted your understanding of scientific concepts and your overall academic achievement in science?

4. Overall, do you feel participating in inquiry-based activities, such as case studies and lab design, was a valuable experience for you? Explain.

5. Do you like learning science through inquiry?

6. Do you think that learning science through inquiry is effective? Why or Why not?