

POINT LOMA NAZARENE UNIVERSITY

**Use of inquiry based-pedagogy during organism dissection to improve scientific
questioning skills of middle school students**

A thesis submitted in partial satisfaction of the
requirements for the degree of

Master of Science

in General Biology

by

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2014

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2014

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Acknowledgement

I would like to thank Dr. Dianne Anderson for all her help, support and encouragement. Her patience and understanding have allowed me to complete this project.

I am also very grateful to my family and the Nazareth School Science students for their constant encouragement and enthusiasm.

Abstract of the Thesis

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Although many teachers consider dissection an important educational tool, it is mainly used to reinforce information previously gained by studying anatomy and physiology. Rarely is inquiry-based pedagogy used with dissection; instead the activity is mainly teacher-driven and worksheet-based. The purpose of this study was to examine the improvement in student question writing skills when a limited inquiry-based approach was used. Specifically, this mixed-method study aimed to assess scientific question formation in the context of multiple animal dissection labs in a diverse middle school science class with 33 students. Four dissections were conducted to explore the concept of adaptive evolution of both invertebrates and vertebrate organisms within their specific habitats. Students wrote pre-lab questions about animal adaptations, chose one question to answer, completed the dissection, and then wrote an answer to their chosen question based on the dissection. The results were collected and used to generate quantitative data (scores on the questions) and qualitative data (analysis of written content). There was no statistically significant difference between the means for all scientific questions written

by the students for the first dissection and the last. Although, this comparison did not show significant results for improvement of scientific question writing skills over time, further analysis did demonstrate a positive improvement in the quality of the questions chosen by students.

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Introduction

“Positive experiences in secondary school science might lead more students to choose careers in mathematics, science and engineering . . .so that they might be prepared to tackle problems in the adult worlds of Science and Industry” (Dev & Walker, 1999, p. 636). In an effort to generate just such a positive experience in the study of biology, dissection of both invertebrate and vertebrate organisms has been used to promote interest and engage students. Alternatives to dissection such as diagrams, models or computer simulations, may be very clear and concise, but the actual examination of a specimen can be extremely thought provoking, exciting and challenging thus initiating student enthusiasm in biology.

The traditional purpose of using dissection has always been for memorization of structure and function of organs and organ systems with little emphasis on adaptive evolution, which is how the organism has successfully adapted to its habitat. Although many teachers consider dissection an important educational tool, it is mainly used to reinforce information previously gained by studying anatomy and physiology. Rarely is inquiry-based pedagogy used with dissection; the activity is mainly teacher-driven and worksheet- based.

For an activity to be considered an example of inquiry-based pedagogy, it must begin with a research question. The best format for inquiry instruction recognizes the

importance of question formation and seeks to help students progress to greater inquiry skills through a series of graduated steps (Bell, Smetana & Binns, 2005). An inquiry-based activity must also assess the student's ability to answer the research question based on data collection and analysis (ibid). There are many excellent hands-on activities routinely performed in science classrooms. However, most cannot be considered to be inquiry labs as they do not involve a research question or merely have an implied question as part of the activity. Additionally, not all inquiry activities are equal and the concept of different levels of inquiry (from limited to completely open) has been discussed since 1962 (ibid).

An example of a low-level inquiry activity would include a teacher-presented question with a prescribed procedure and solution. This traditional activity format might be manipulated to become inquiry centered by performing the lab prior to the discussion of the concept being taught. Additional changes would also involve requiring students to design or select a procedure for an investigation based on a question which they have helped formulate. This restructured activity could then be considered to be a type of guided or limited inquiry as the step-by-step directions are removed, as well as the predetermined question. Open inquiry is at the highest level where the student independently proposes the problem, methods, and solution with the teacher as a resource and guide. However, regardless of the level of inquiry; writing questions is a critical aspect of inquiry-based pedagogy.

Therefore, to promote all levels of inquiry-based instruction, student writing skills (especially the ability to construct well-defined scientific questions) must be emphasized

and practiced. Question writing can promote critical thinking skills and challenge student misinformation (Baker, Barstack & Clark, 2008). Students may be provoked to ask higher-level inquiry questions if they are confronted with conflicting or surprising evidence (ibid). Dissection labs could provide such an opportunity when presented in an inquiry-based format. Unfortunately, the majority of dissection laboratory exercises and reports are traditionally “prescriptive” (or directed) activities and mainly an exercise in memorization (Hand, 2004).

Accomplishing the redesign of any science activity, and specifically a dissection lab, to incorporate inquiry skills can be challenging for teachers. Typically, science fair projects are perhaps the most common form of an open inquiry activity in science classrooms. Students investigate student-formulated, topic-related questions with their own procedures (Bell, Smetana & Binns, 2005). Assuming that the student completes the activity without significant involvement of parents, the experience is (at this time) the only example of open inquiry format in most middle school classrooms. One solution would be to develop a modified inquiry-based pedagogy specifically to improve the understanding of adaptive evolution and the skill of question writing simultaneously, then the transition from traditional dissection activities based on pre-formatted material might be accomplished.

Although inquiry-based activities have been the template for science education reform since 1996 with the publication of the U.S. National Science Education Standards (National Research Council, 1996), adapting a dissection lab to this format poses a number of barriers and has yet to be accomplished. Additionally, a complete open-

inquiry format presents a significant number of safety and ethical issues, therefore only limited or structured inquiry pedagogy is possible with dissection labs. However, some of the main challenges confronting teachers who attempt to revise labs to a limited inquiry format are concerns over safety, maturity of students, time constraints, heterogeneous inclusive classrooms (Palincsar, Magnusson & Colins, 2001) and lack of effective science writing skills which can limit the complete transformation of these laboratory exercises.

The purpose of this study was to examine the improvement in the quality of written student questions when a limited inquiry-based approach is used. Specifically, the study aimed to assess scientific question formation in the context of multiple animal dissection labs in a diverse middle school science class. According to Yager and Akcay (2010), an inquiry-based format to science teaching will promote critical thinking skills and encourage learning. In their article on inquiry, the authors stated that, “They (the students) must learn to ask new and more focused questions that require thought and analysis” (p. 6).

Theoretical/Conceptual Framework

The theoretical perspective for this study is utilizing constructivism theories. The constructivist theory states that learning is an active process of creating meaning from different experiences (Von Glasersfeld, 1993). Students will learn best by trying to make sense of something on their own, with the teacher as a guide to help them along. Although the concept of inquiry-based instruction seems new and revolutionary to many teachers and students, the philosophy on which this type of instruction is based actually

had its foundation back in the 1800s with psychologists such as Piaget, Dewey, Vygotsky and others.

Piaget stated that to understand the development of knowledge, we must start with an idea or an idea of an operation. His theory proposed that “knowledge is not a copy of reality, but to know an object is to act on it whether through modification of or transforming the object and to understand the process by which the object was transformed” (Piaget, 2003 reprinted from 1963 p. 15). He believed that the main purpose of education was to help intellectual development to occur through the construction of thinking skills (logical structures) that develop through experiences. Therefore, for the student to modify their knowledge requires active learning or the ability to investigate with hands-on experimentation.

The use of hands-on activities within the classroom has been attributed to John Dewey. Dewey stated in 1916 that the most natural way for children to learn is by doing and he observed that children must be guided and provided with appropriate learning experiences if they are to develop the habit of “critical examination and inquiry” (Colley, 2008). Dewey’s name has been used to justify out-of-school learning activities, project-based learning, and apprenticeship because they all involve learning through experience (Wong & Pugh, 2000). John Dewey proposed that no experience has a pre-ordained value (ibid). Thus, what may be a rewarding experience for one person could be a detrimental experience for another. The value of the experience is to be judged by the effect that the experience has on the individual's present, their future, and the extent to which the individual is able to contribute to society. Educators should organize the

subject matter such that it takes into account student past experiences and provides them with additional experiences, which will promote educational growth (Wong & Pugh, 2000).

Vygotsky (1978) proposed that the most important aspects of a teacher's role is to provide materials for students to observe and investigate as well as to help them ask the right questions and to communicate their thinking and develop ideas. Simply increasing the number of hands-on activities in science is not the solution to science literacy.

Allowing students to participate in lab related opportunities such as dissecting various preserved organisms, can strengthen their ability to formulate their own scientific question writing skills while providing an experience which is engaging and challenging. "The importance of the constructivist approach to science learning lies in its emphasis on the students' direct experiences with the physical world and its recognition of the active construction of meaning that takes place whenever students interact with their environments" (Syh-Jong, 2007, p. 67). The student's ability to construct their own knowledge by working with biological specimens to examine adaptations which have promoted the organism's survival in the "physical world" can be utilized by teachers to develop inquiry-based laboratory activities. Implementing a structured inquiry procedure with such labs would require students to work to solve questions that they have proposed, rather than receiving instructor-generated questions and conclusions.

In an article entitled *Questions and Answers about Radical Constructivism* (1993), Ernst von Glasersfeld (1993) explains that learning requires active involvement of the student in both cognitive and sociocultural aspects. Instead of responding to stimuli

as a behaviorist might, a student will make interpretations of their experiences and develop the experiences by building upon prior knowledge. Both radical constructivism and constructivists theories require disequibration to occur before the student can learn. If information gained from new experiences is contradictory to a student's current knowledge of a concept, students struggle with disequibration before reacquiring equilibrium.

According to von Glaserfeld (1993), students are responsible for the ultimate development of their own comprehension and reality of the situation. Achievement of lasting learning would be to require active participation by the students. Therefore, experiments which allow students to explore should be conducted. The teacher should be a guide and allow students to struggle with answers to questions they (not the teacher) pose. The teacher therefore becomes a facilitator of the learning process and not the controller of it. With guidance from the teacher, students can come to their own understanding of the concepts. This then is a basis for inquiry pedagogy. Simply directing the inquiry (rather than supplying answers) has the potential to create a struggle for the students in trying to comprehend various concepts. The disequilibrium generated by the internal mental conflict, stimulates cognitive growth when existing schemas are challenged.

Students must also engage in such higher-order thinking tasks as analysis, synthesis, and evaluation (Bonwell & Eison, 1991). Strategies promoting active learning should be defined as instructional activities which involve students in these higher-order tasks and not simply performing the exercise. Research has shown that a significant

number of students have learning styles best served by pedagogical techniques other than lecturing (Freeman et al, 2014)). Studies evaluating students' achievement have demonstrated that teaching strategies requiring active learning are comparable to lectures in promoting the mastery of content, but superior to lectures in promoting the development of students' skills in thinking and writing (Bonwell & Eison, 1991).

Therefore, a constructivist might consider the definition for ideal science teaching as one that would encompass both active learning and the use of the inquiry-based approach. Active learning applied to scientific activities should require students to think through and perform their tasks within an inquiry format. Inquiry pedagogy could then be demonstrated by allowing students to pose their own scientific problem, determine the procedure, carry out the experiment and discuss results. In doing so, the students would be promoting their own learning experience in a step-by-step development of their knowledge without the direct influence of the teacher.

Literature Review

Inquiry in the classroom

Inquiry in the classroom is an approach to teaching which requires learning to be based on student-generated questions. Encouraging students to practice problem solving and creative thinking is far better than testing their ability to memorize (Baker, Barstack & Clark, 2008). Yet, breaking from traditional instructional techniques is often easier said than done. Curriculum formatted to inquiry-based learning has been developing since the 1960s, however is as yet to be fully utilized in the majority of science classrooms today (Freeman et al, 2014). The idea of inquiry-based science education actually began with the launching of the first space satellite, Sputnik, in 1957 by the Russians. As a result of this launching, a tremendous outcry came from the American public as to why the United States was not the first to have placed a satellite into space. The blame fell on the public school system and an examination of the science and mathematics curriculum was critical of what was taught within most schools (Luft, Bell & Gess-Newsome, 2008). Reforms were then proposed over the next several years to mend what was perceived as a “failing” curriculum. Some changes were brought about by innovations to the K-12 science curriculum in the form of curriculum specialists, teachers, scientists, and mathematicians all proposing significant improvements to both mathematics and science educational programs. One such reformer was Joseph Schwab (1909 – 1988), who was a major contributor to the Biological Sciences Curriculum Study (BSCS) high school biology course materials. He had worked at the University of

Chicago for over 50 years at what was called a “Lab School” established by John Dewey (Luft, Bell & Gess-Newsome, 2008).

Schwab presented a lecture at Harvard University in 1962 regarding teaching “enquiry”, which was the word he preferred to use instead of “inquiry”, because he was opposed to the way in which psychologists were promoting the idea. The premise of his lecture was to point out that “teachers misrepresent science when they present it as rhetoric of conclusion or as a finished product” (as quoted in Luft, Bell & Gess-Newsome, 2008, p. 25). He felt teachers should show students how scientists view ideas and how science concepts can be changed and will continue to change over time. He also stressed that students must be “active in the laboratory and that they develop their critical thinking skills by analyzing the works and original papers of scientists” (as quoted in Luft, Bell & Gess-Newsome, 2008, p. 26).

Without significant and widespread reform taking hold, once again in the 1980s science education was blamed for the inability of the United States to compete academically with Japan. The Japanese had become a leader in the world economy with the manufacture of many innovative electronic devices and automobiles. A report released in 1983 (called “A Nation at Risk” from the Commission on Excellence in Education), once again called for reform of science and math curriculum in K – 12 with the following statement: “our education system has fallen behind and this is reflected in our leadership in commerce, industry, science and technological innovations” (as quoted in Luft, Bell & Gess-Newsome, 2008, p. 27). The report recommended that educational goals for students should be to develop more of a relationship between science,

technology and society. No mention of emphasizing inquiry-formatted labs (as a way of improving science education) was introduced and in the 1970s to 1980s science educators were encouraged to focus on social issues and values as a remedy for the deficiencies in science proficiency.

However, the U.S. National Science Educational Standards (National Research Council, 1996) promoted a redirection back to the emphasis on inquiry pedagogy in 1996. The importance of inquiry in the NSES was stated as follows:

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. 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.

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. . . .

Although the Standards emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understanding, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry . . . ((NRC, 1996, p. 23).

In 1998, the California Science Content Standards for Grades K – 12 also called for improvement of science curriculum to utilize a more inquiry-based format. The “push” for a conversion to this type of instruction was evolving as a result of the

perceived failure of traditional forms of instruction. However, the successful transition to inquiry-based pedagogy has yet to be accomplished within most science classrooms.

Creating inquiry-based experiences in a classroom setting presents numerous challenges for most teachers and it is those challenges that restrict some teachers from diverting from traditional teaching methods (Jackson, 2008). Many teachers find it difficult to begin a process of scientific inquiry within the classroom because they need to relinquish some control as the focus of learning is not teacher-directed, but student-oriented. No longer are lesson plans with preconceived conclusions a basis for science instruction. For many teachers this can be an uncomfortable experience as it leads to a less controlled and predictable outcome for various science experiences. The teacher should redirect their instructional emphasis to assisting students in developing skills that can promote the inquiry process, rather than dispensing information (Jackson, 2008).

There are also practical difficulties associated with active student-centered instruction. According to Debbie Jackson author of “Facilitating an inquiry-based science classroom” (2008), obstacles to scientific inquiry include: time required to plan and conduct the inquiry, the materials and facilities needed for the inquiry, safety issues, one student in a group completing all of the work, getting student’s attention and makeup work for students who miss the inquiry-based activity. Ultimately, the teacher must have achieved a level of competency for the subject matter through their degree or advanced degree achievement and professional development which allows them to be used as a resource for students (Jackson, 2008).

However, these challenges are not insurmountable. In the article, the author makes the suggestion that one way to overcome the physical demands of inquiry-based instruction would be to improve teacher organizational skills (Jackson, 2008). Having all materials and equipment placed in boxes or trays and made available to students in an easily accessible area is important to helping the students accomplish their experimentation. Another challenge is safety which is probably the most important concern to be controlled in an inquiry setting and one occasionally overlooked, specifically at the elementary level (Jackson, 2008).

Each teacher needs to assess their particular safety issues within the classroom to insure the protection of the students working with the inquiry process. Some of the safety concerns which the teacher may need to be focused on within their classroom setting are: availability of water, storage of equipment, position of or lack of lab tables, and maturity levels of the students (especially in regards to their behavior). Special needs students (whether possessing physical or learning disabilities) could require additional changes to the classroom set-up in order to ensure safety of all students while implementing an inquiry-based lab.

Another consideration for success in promoting the transition from traditional instruction to an inquiry-based format would be to maximize classroom rules and guidelines designed to manage varying numbers of students in the science laboratory area (Jackson, 2008). Teachers may need to expand their already existing class rules to emphasize cooperation and increase the expectation of productivity within the classroom. Additionally, the role of the teacher will change from a director of classroom activity, to

that of a guide and mentor providing supporting information along with reminders such as to how to manage materials and transport them in a classroom which is likely to be very congested. Finally, motivation of the students rather than control and subject content must be the greater priority to allow students to become successful when utilizing the inquiry process.

The challenges presented by the physical and behavioral environment are not the only obstacles to be encountered when implementing an inquiry format. The need for students to direct their own learning requires the ability to effectively and proficiently communicate to their teachers through their writing. This skill must be emphasized, practiced and promoted in the classroom in order for students to gain proficiency in areas such as science question formation.

Development of writing skills in the context of science

Communication is a critical skill necessary for students during scientific learning. Thus, teaching communication is essential to the process of inquiry-based learning in the classroom. Helping students become effective communicators, whether verbally or through their writing requires teachers to guide the students in developing ideas and discussing evidence. Moreover, to begin any inquiry, a clearly-communicated question must be posed to direct the investigation. It is that question which will guide the student's evaluation of evidence or data obtained from their actions.

“The constructivists emphasize that forms of language facilitate students' meaning or constructions. Language is a means of actually performing science and constructing scientific understandings; language is also an end, in that it is used to communicate inquiries, procedures and scientific understandings to other people” (Syh-Jong, 2007, p. 67).

Thus, according to the constructivist theories, language in relation to inquiry is a critical part of learning. The need to strengthen the writing ability of students is apparent to all teachers and can be incorporated into subjects science with adjustment to the laboratory curriculum. The National Standards define “full inquiry” as a process in which students (a) pose a productive question; (b) design an investigation directed toward answering that question; (c) carry-out the investigation, gathering the applicable data in the process; (d) interpret and document their findings; and (e) publish or present their findings in an open forum (Huber and Moore, 2001).

Much of secondary school science tends to focus on the products of scientific inquiry, not the process. This focus obscures the importance of questions in inquiry which allow for the building of science knowledge. Generally, the teacher introduces the context of the information or knowledge which students are required to understand with a presentation, lecture or activities. If the manner in which the material was presented could be changed to become an opportunity for students to develop their own questions, students might strengthen their scientific writing skills as well as their understanding of science concepts. Yet, these opportunities are often overlooked. More importance (mainly due to pressure from school administrators), has been placed traditionally on standardized test scores or grades rather than providing classroom opportunities for inquiry-based activities in science classes.

Question posing is an integral part of inquiry-based instruction and is a skill which requires continual use and refinement (Wolf, 1987). It should remain a focus for

all levels of science education (ibid)). If inquiry-based instruction is to become the main part of science education, then students must be taught about the types of questions that serve to guide scientific inquiry and how they are developed.

The range of questions that exists today (Wolf, 1987) has been expanded upon from the traditional classification of learning goals cited in Bloom's taxonomy. In 1956, Benjamin Bloom suggested ways for application, analysis, synthesis and evaluation of knowledge through the use of questioning, which was primarily intended for teachers rather than students. However, expanding on Bloom's learning goals has presented a range of questions such as: inference, interpretation, transfer, questions about hypotheses and reflective questions which can be modified for student application (Wolf, 1987). Inference questions are those that simply require filling in missing information and interpretive questions demonstrate an understanding of the information and ideas studied. Transfer or creative thinking questions, ask students to take their knowledge of a subject to "new places" and reflective questions or are ones from which hypotheses can be generated and require students to use abilities of critical thinking to ask: "What does this leave me not knowing?" or "What things do I assume rather than examine?" According to Wolf, teachers need to present learning situations that allow for students to ask questions, as a way to practice the very essence of inquiry which is question formation. The author goes on to state that many teachers rarely pose questions other than the "read-it-and-repeat-it" level and as a result students are not familiar with answering other types of questions, let alone creating (on their own) those which demonstrate a level of critical thinking (Wolf, 1987).

Given that every investigation begins with a question, scientific writing skills may be developed by teaching effective scientific questioning skills. Students need to learn how to frame only questions that are investigable. Very often, students simply rely on writing questions that require only a “yes” or “no” answer. As Wolf (1987) describes, in an early study on questioning done in 1912, “two-thirds of the questions written by students required only a direct recitation of textbook material and now seventy years later, after the original study, research suggested that only sixty percent of the questions students write require factual answers, twenty percent concern procedures, and the remaining twenty percent require inference, transfer, or reflection” (p. 9).

Although the study mentioned was written in the late 80s, the conclusion provides insight even today as to the importance of student development of question writing skills. Evidence from the study demonstrated that students are primarily listening and responding to questions in classrooms and as a result, they will have a difficult time formulating and writing their own. To direct an investigation by composing a question to examine a particular scientific problem requires practice and experience in writing appropriate scientific questions. The teacher needs to redirect the focus of the learning environment to question formation and away from merely answer generation. Students need opportunities to pose questions that help them develop an understanding of phenomena in nature (Luft, Bell & Gess-Newsome, 2008). The orientation toward writing questions allows students to reveal their level of understanding and generate interest for a particular topic. More importantly, when students generate their own questions they are more often interested in answering them.

The type of question a student writes is also of significance. Thus an important educational goal is to help students thoroughly examine a topic as well as the variables that affect that situation and to pose critical thinking investigative questions. In general, the use of the term “critical thinking” is used to describe the use of those cognitive skills or strategies that increase the “probability of a desirable outcome, thinking that is purposeful, reasoned, and goal-directed—that kind of thinking involved the solving problems, formulating inferences, calculating likelihoods, and making decisions when the thinker is using skills that are thoughtful and effective for the particular context and type of thinker task” (Halpern, 1996, p.6).

Other types of questions may be useful in scaffolding to the higher level of critically thinking questions (ibid). The lower level or what might be termed identification and function questions can simply be answered with information from discussions or research. Higher level questions such as those which are observational can be generated from examining phenomenon in nature, along with a basic understanding of the science regarding that phenomenon to help formulate the question. These questions can describe regularities or irregularities in nature (ibid) and lead to additional questions that may become the basis of an investigation and thus may improve or add to our knowledge. Such questions are to be considered “critically thinking” questions which can often be the precursor to a research or experimental questions (ibid).

When instructors rely less on prepared materials with established answers, students may become more effective in asking and communicating questions as they must practice the skill. The benefit to students learning to pose their own questions is a creative

or inventive outcome. “Being asked and learning to pose strong questions might offer students a deeply held, internal blueprint for inquiry. . .” (Wolf, 1987, p. 10). If students are to develop a better understanding of inquiry, then the teacher needs to assist them in developing questions that can be addressed using scientific inquiry.

The usefulness of dissection in the classroom

Dissection can be used as a context for students to learn to write good questions. Historically, dissection was a tool used by scientists to investigate the forms and functions of physiological structures as well as a tool used in the pre-professional practice of occupations such as medical doctors and veterinarians (Hug, 2005). This tool was taken up by schools as a way of teaching concepts about comparative anatomy. However, the practices around this historic activity have not evolved with the changing values of the school environment (Hug, 2005). Neglect to change has also been evident in the application of writing skills and inquiry-based pedagogy with dissection activities. Dissection, a high interest activity could be very useful to the instruction of scientific writing skills, especially improving student questioning abilities if used appropriately. Although alternatives to specimen dissection, such as virtual computer programs, have received more attention in recent years, the use of actual organisms still provokes a level of high interest which engages the majority of students.

Although computer programs are clear and concise and the computer simulations are also considered by students to be fun to manipulate, the actual examination of multiple specimens can present dramatic structural variations. Student observation of these variations during animal dissection can create an experience that is thought

provoking, exciting and challenging as it visually promotes the understanding of adaptive evolution. A great proponent of looking at the natural world (especially what is often considered familiar) was Charles Darwin. He found that what is accepted as common place can become deeply strange by which the search for explanations can become extremely fascinating and that is what then develops into science (Keynes, 2009). Students are often very “familiar” with the organisms that are to be dissected, but have not looked at those organisms or studied the specimens in a manner that could be intriguing. Using dissection as a motivational activity in which students generate questions as they examine an organism based on its adaptations for a particular environment may promote a level of fascination and thus create a higher level of interest for the concept of adaptive evolution. Students thinking about challenges to an organism’s struggle for survival in a particular habitat may stimulate the production of their own scientific questions, rather than simply answering a set pre-formatted dissection questions.

Presently, many teachers use dissection as a tool to teach comparative anatomy of invertebrate or vertebrate organisms. While students learn best through inquiry-oriented, hands-on teaching and learning, the majority of dissection labs are not open-inquiry labs but rather, verification labs, where the answer is already known (Hug, 2005). Developing an activity around the issues challenging an organism within its habitat can help students recognize through close observation of their various adaptations how an organism has gained the ability to survive. This is an important aspect of applying inquiry-based instruction to dissection (Bernstein, 2000).

Using dissection as a single activity is another limitation of current approaches to dissection in the classroom. The dissection of a frog or fetal pig to summarize the various units of study regarding human anatomy generally signals the culmination of that unit for most middle school or high school teachers. It is often the signal for the end of study on a series of chapters or can be considered simply as a “rite of passage” for students finishing up a Biology or Life Science course. Unfortunately, when this unique activity is used only once (as tradition generally dictates), it is considered by most scientists as a waste of a very unique educational opportunity, (Bernstein, 2000).

According to Bernstein, to look inside (an organism) should be done often and with many different specimens. It should be a part of an ongoing discussion and preparation which can integrate many areas of study, not just anatomy and physiology. Dissection is another way to teach the process skills of science, such as questioning and allows students to “see” and inquire about internal or external aspects of an organism which might otherwise be unknown or hidden to the student (Bernstein, 2000).

When students take more time and care with dissection activities and study several organisms, not just one, they are more prone to show greater interest and ask focused and critical questions over time. As students are required to think more about the organisms, such as their survival within a particular environment due to certain adaptations, they are more likely to look carefully inside and care that at one time this animal was once alive. With emphasis on adaptive biology rather than simply identification of anatomical structure and function, greater respect for these animals is

promoted which is often difficult to accomplish with only one dissection (Bernstein, 2000).

Natural selection and adaptive evolution

The success of specific adaptations promotes survival not only of an organism, but of that particular population of the species. In 1858, Charles Darwin and another British biologist, Alfred Russel Wallace, proposed an explanation for how evolution can occur in nature based on successful adaptations (Orr, 2008). Charles Darwin went further in 1859 and described the mechanism in his book entitled *The Origin of Species*. This mechanism was called “Natural Selection” and is the process by which an organism survives based on being better adapted to its environment and more likely to survive and reproduce than other members of the same species.

Natural selection requires the following: overproduction, competition and variation (ibid). In many species, large numbers of offspring are produced where there are not enough resources such as food, water, and living space and only those capable of competing for those resources survive. Darwin knew that many species produce far more offspring than could possibly survive. If all were to survive there would soon be over crowding within a particular habitat. Charles Darwin suggested that with natural selection, some of the offspring are better able to compete for food and resources than others. However, competition may not always involve environmental resources, but can be related to effects of predation or inability to find food resources (Brooker, Widmaier, Graham & Stiling, 2008). Those that were “selected” for survival had specific

adaptations or variations such as color difference for improved camouflage or more effective ways of eating foods that other animals may also consume.

Darwin inferred that within a given population, individuals whose characteristics adapt them best to the environment are most likely to reproduce and leave offspring than less fit previous organisms. Therefore, the diverse forms of life have arisen by descent with modifications from ancestral species and the mechanism of modification, for the most part, has been natural selection working over enormous periods of time (Campbell, 2005).

Examining the diversity of life is difficult for students to accomplish with significant understanding, especially in regards to variations within different species. Often, the only resource available to explore that diversification is the textbook or on-line information. Using dissection as a way to examine different environmental adaptations for various species, instead of simply identifying anatomical structures and memorizing their functions, could be an important educational application. Many scientists have stated that the use of dissection within the classroom has been underutilized (Bernstein, 2000). By taking this high interest activity and restructuring it to not only reflect the use of a limited inquiry-format, but also an examination of how adaptive evolution has impacted various species, could transform dissection into an even more valuable educational tool.

Biologists regard an organism as being adapted to a particular environment when it reproduces and survives better than other, slightly different organisms in that same environment. The successful transmission of a particular adaptation for a given

environment to future generations is adaptive biology (Campbell, 2005). Adaptations refer to traits that enhance the survival and reproductive success of the organisms that possess them. The process by which certain traits become more common in the population is a result of genetic variation within the population, followed by natural selection.

Structural adaptations are the physical features of an organism such as shape, body covering (exoskeleton), defensive or offensive mechanisms. The organism's internal structure, such as its type of gas exchange or circulatory system can also be considered a type of structural adaptation (Brooker, 2008). Although behavioral adaptations would also fall under the area of adaptive biology, this area of the concept was considered by the students in this study, as access to live organisms was limited. Several examples of behavioral adaptations would be an organism's method for searching out prey, finding a particular type of food and females only responding to signals of their own species (Campbell, 2005). Students can infer such behaviors by observation of the external feature of each preserved organism studied.

Physiological adaptations are ways in which an organism performs special functions such as making venom or secreting slime (Brooker, 2008). An example would be the earthworm's use of mucus to promote oxygen exchange. There are however, more general physiology functions such as growth and development (metamorphosis in the frog), temperature and other aspects of homeostasis which can be considered adaptations. Adaptation, then, affects all aspects of the life of an organism and how that organism evolved to be successful in its particular environmental niche. For adaptations to

develop, they must happen randomly as an ideal phenotypic change for a given external environment.

Students in middle school are taught that mutations of the Deoxyribonucleic Acid molecule (DNA) with possible deletions, substitutions or additions of the molecule's nitrogen base sequence can result in genetic change. Although most mutations generate a neutral effect on the organism, some generate adaptations that are beneficial to the survival and or reproduction of an organism. In addition, some random mutations may have a harmful effect to an organism that could result in a physical defect, disease or death. One of the problems with teaching this area of evolution is the connotation that most students have regarding adaptations. It is often misconstrued by the student to mean simply changes that occur over a lifetime and not the biologist's use of referring to population phenomenon where the population as a whole changes over many generations of natural selection (Brooker, 2008).

Inquiry pedagogy and Animal Dissection

The opportunity for active learning is key to promoting inquiry-based pedagogy with animal dissection and would allow the student to develop their own questions of interest regarding both external and internal anatomical features as well as how those structures promote survival. Active learning should involve students asking questions, comparing answers to what is known, using evidence to develop explanations, considering alternatives, and making ideas public while recognizing that explanations may change following discussion (Ueckert, 2008). Presently, highly structured

laboratory experiences involving dissection leave little room for the student to create their own questions and predications about the organisms used.

Most students entering middle school have not had formal classroom experiences or discussion on such topics as adaptive evolution, especially in regards to animal anatomy. The majority of dissection labs at the secondary level are primarily verification labs in which the answers are already known (Hug, 2005). By developing the activity around the issues confronting the structure and function of an organism (their adaptations) within a particular habitat, students can refer to their prior knowledge, then modify their questions based on the evidence they acquire from participating in the dissection. Some students experience difficulties in generating questions and formulating their own problems since they are used to being provided with well-defined problems which already have solutions. By converting the traditional dissection lab format to a limited inquiry-based pedagogy, the opportunity will exist for students to practice question formation while specifically examining an organism regarding the concept of adaptive biology.

Alternatives to dissection in the classroom

In recent years, the educational value of student's performing real dissections of preserved organisms has come under scrutiny and become the topic of tremendous debate. Valid concerns over safety, destructive nature of the dissection process and negative reactions by students are just several of the issues that surround the controversy over dissection. Several states have implemented legislation to guarantee that students have the right to opt out of picking up a scalpel at the laboratory table (Cavanagh, 2004).

Students who decline to dissect, sometimes do so for religious reasons or because the procedure makes them physically uncomfortable. Under a Virginia law, schools are required to make it clear in course guidelines or syllabi that students do not have to take part in dissections (Cavanagh, 2004). Massachusetts' legislators approved a measure that would require the state board of education to draw up guidelines for alternatives, so that students who do not want to take part in dissections may have other choices. California also has taken a similar position of choice for students, in regards to dissection since 1999 (Duncan, 2008).

Alternatives available for students are varied such as plastic models of the organism and computer simulations (either online or CD-ROM). These advances in technology caused many animal rights advocacy groups such as PETA (People for the Ethical Treatment of Animals) to declare the use of real animal dissections in a classroom as unnecessary and even view it as a form of cruel experimentation. Their position reflects the opinion that this educational tool is more likely to offend students, rather than develop their knowledge of anatomy (Cavanagh, 2004).

Safety issues are also a main concern of teachers using dissection of organisms in their lesson plans. Special concern has been directed toward the chemicals used to preserve the specimens and is often the primary reason teachers do not use animal dissections as part of the curriculum. The use of such chemicals such as formaldehyde and formalin has caused the National Science Teachers Association (NSTA) to adopt a revised position statement for the responsible use of dissections in the science classroom

(Roy, 2007). Under the “Dissection” section, the NSTA calls for more research to determine the effectiveness of animal dissection activities and alternatives (Roy, 2007).

Studies conducted on the effectiveness of virtual and real animal dissections are conflicted. Research has found that online computer simulations (Dev and Walker, 1999), CD-ROM programs (Amberg, 2001), and interactive video-discs gave significantly more positive responses on post laboratory questionnaires than from actual laboratory investigations. Positive results were reflected in levels of knowledge, understanding of experimental results, or general satisfaction with what was taught (DeVilliers & Monk, 2005). Results showed no significant difference between laboratory investigations and simulations regarding a student’s understanding of principles, levels of interest, and levels of confusion or boredom (DeVilliers & Monk, 2005). Any dissatisfaction with the simulations appeared to be regarding the students missing formal instructions as well as the lack of handling specimens and equipment (DeVilliers & Monk, 2005). However, other studies have found that students who used the computer program did not score as well in the laboratory practical as the students who used the real animals (Cross & Cross, 2004). Students not only gain an understanding of anatomy, but also develop a sense of responsibility and respect for the animal that they are using as a learning tool. Therefore, there are definite advantages to using actual animal dissection. Even authors DeVilliers & Monk commented in their article that sensory involvement in science education can be a very powerful learning experience and a definite advantage in the use of animal dissection. The alternatives to dissection such as computer simulations do not provide the same sensory experience as viewing actual animal tissues and organs.

Other advantages can be in the areas of visual-spatial thinking and realism which are not gained in the use of alternatives to dissection. The ability to rotate, manipulate and envision objects during dissection greatly contribute to visual-spatial perception (DeVillers & Monk, 2005).

Research Question

The hypothesis reflected the expectation that there would be an improvement (over time) of student question writing performance (between the first dissection and the last dissection), as the students continued to practice this skill with each of the four dissections that they conducted. Dissection is a popular technique for teaching certain scientific concepts, but rarely used in an inquiry-based approach or for the purpose of strengthening scientific question writing skills. The purpose of the present study was to examine the usefulness of dissection in regards to teaching the understanding of adaptive evolution within a limited inquiry format and secondly, to note any improvement in the quality of questions posed by students to direct their examination of the organism. The use of dissection applied with a structured inquiry based format to emphasize, not only evolutionary concepts, but development of scientific question writing formation led to the following research question: Is it possible to improve student scientific writing skills beginning with their ability to formulate questions in an effort to promote an inquiry based format for animal dissection labs? When students focus on an organism's physical adaptations (not simply comparative anatomy) within the context of a structured inquiry-based format, it can be hypothesized that there would be an improvement in their scientific question writing skills over time.

Methodology

Research Design

This was a mixed method study utilizing both qualitative and quantitative data to enhance understanding of student questioning related to the labs. The students were to write down questions as pre-lab work, in their lab books prior to the actual dissection. These questions reflected the student's inquiries about the organism with a focus on adaptive evolution. This data was collected and used to generate both quantitative data (scores on the questions) and qualitative data (analysis of written content). The qualitative data was used to explain the quantitative data.

One student-generated question of the three was selected by the student to be answered at the completion of each dissection lab. The student was to examine the organism with the intent that information would be acquired which would allow them to answer their own written question. A rubric devised by the researcher was used to analyze the quality of the student's questions based on their levels of critical analysis. Examples of questions that were limited to only identification and comprehension of structural function were reviewed in class prior to the dissection module. Class discussions were conducted to improve the way in which questions could be formatted to emphasize the importance of adaptations that may provide an evolutionary advantage for each organism which was dissected.

Setting and Participants

The test class was composed of 33 seventh-grade middle school students ages 12 – 13, in a biology class at a private, parochial school in San Diego. All of the students were under eighteen years of age and therefore fell into the protected age group which required a parental/guardian permission form to be completed prior to the student participating in the study. A copy of the permission form can be found in Appendix A. The principal was made aware of the study and approved it. A copy of the letter which was sent for purposes of the IRB approval process can be found in Appendix B.

The students in the class being studied represented all three achievement levels (high, average and low as determined by their percentage of the total possible points for tests, quizzes, and lab work) constituting a heterogeneous multi-level ability population. Students with learning and physical disabilities (hearing loss) were also part of the classroom population. Both ethnically and economically diverse were represented including African-American, Asian, Hispanic and Caucasian students whose families come from various educational backgrounds (with both professional and non-professional careers). Variables such as ethnic and economic background are not part of the focus of the research question.

Parental/ guardian permission was obtained before students were allowed to participate in this study. A permission form requiring a parental/guardian signature was sent home with each student. Since all students returned a completed form indicating

permission for participation in the study, the entire class conducted four dissections as part of the regular classroom activities.

Student's confidentiality and anonymity were protected. Each student involved in the study was assigned a number for the researcher's data records and tables. A Master list was created and contained the student's name and assigned number which was maintained by the researcher. Only the researcher had access to the Master list.

Dissection specimens and supplies

The dissection specimens (earthworms, squid, crayfish and frogs) were purchased from Carolina Biological Supply Company using the middle school science budget allocation. Carolina offers specimens preserved in a solution called Carolina's Perfect Solution, a fixative that is nontoxic and free of dangerous off-gassing. After being fixed in a special chemical that's completely consumed during fixation, these specimens are rinsed and stored in formaldehyde-free preservative. They are considered to be "formalin-free" specimens. The specimens have a pleasant odor, resist mold and stiffening. Traditional dissecting equipment was used including dissecting trays, dissecting scissors, forceps, and pins. Students wore protective gear including safety goggles and latex or vinyl gloves.

The classroom study

Four dissections were conducted to show adaptive evolution of both invertebrates and vertebrate organisms within their specific habitats. Each dissection required a least two to three classroom periods of forty-five minutes each to complete. Preserved

dissection specimens of earthworm, squid, crayfish and frog were used in four separate activities. The lesson plans for the research encompassed the following procedure:

Day One focused on a discussion of the reading material pertaining to the adaptive capabilities of the organism that had been assigned to the students as homework. Students commented on habitat and/ or specific adaptations for each organism, based on such challenges as gas exchange, water acquisition, food resources and waste elimination. To stimulate the dialogue, students observed a demonstration of movement for live earthworms and crayfish and video clips of the squid and frog, to view their natural behaviors and adaptations. At the conclusion of these discussions, students (in class) were asked to suggest examples of questions that would explore some of the structural adaptations each organism has for survival in its environment. A particular type of adaptation an organism has and how the structure of that adaptation allows for its survival were concepts which had been discussed. Along with this concept focus on adaptive evolution, improvements for scientific question writing were demonstrated. Afterwards, students were asked to compose three pre-dissection activity questions and write them in their lab books. Lab books were not allowed to go home, ensuring that only students are working on their questions without parental intervention. Students were asked to develop their own questions, but were not penalized should they collaborate on questions with other students. The students selected one of their own questions to answer after the dissection was completed.

Day Two was the actual dissection period. Student safety and clean-up procedures were briefly mentioned at the beginning of each session. Groups consisting of

two students were formed and during this time, data was recorded for the mass and length of each group's specimen and recorded in their lab book. Students recorded the cumulative class data of mass and length to note any variation among the preserved specimens. Graphs were generated and further mathematical analysis conducted at a later class time based on the cumulative class dissection data. The actual dissections were conducted according to a specific procedure with time set aside for students to look at a particular aspect of the organism's anatomy based on their own research question (or the chosen question from the three questions previously written). An example of the procedure tasks include: opening the stomach to find the contents and a sample of the organism's food choice or removing the beak from a squid to examine it more closely. If students were unable to answer their own questions based on the dissection conducted in class, they were to explain the reason they were unable to do so.

Day Three was an over-flow day, allowing extra time to finish the dissection of each organism, should the lab procedure not be complete during the previous class period. Most students needed this over-flow time.

Day Four was used for students to review their pre-dissection questions and answer the one question of their choice. Notebooks were collected at the end of day four, and questions graded (only for the purpose of this study) according to the rubric shown in Table 1.

After writing all three questions on Day One, each student chose one to use as an inquiry format for their dissection procedure and a guide as to acquiring specific knowledge of the organism being dissected. After each dissection, lab books containing

the students' work were reviewed and the three written questions evaluated for improvement of question writing skills. The written answer to a particular question chosen by each student was also scored by using a different rubric to assess the student's understanding and application of the concept of adaptive evolution (Table 2). All scores for the questions and answers were recorded into the data tables by numbers assigned to the students for the purpose of this study. The scoring was only for the purpose of data collection and had no impact on the student's grade for the individual activity or total class work. This evaluation was not communicated to the students. Students did not share lab books with other students in the class nor were these lab books taken home. All books were collected at the end of the study and archived by the researcher.

Mechanics of implementing the study

This study was conducted as part of the normal classroom activities. All materials were supplied to the students and no additional time was required other than normal classroom time. The Lab Notebook is actually a composition notebook purchased for each student by the researcher. The students participating in this study and their families did not incur any additional expenses.

All activities of organism dissection and science writing were conducted in the Science Room. The room was always accessible to other students, teachers, the administrative staff and the principal. There was only minimal risk of injury to students who did not follow instructions during each lab, as all students were aware of safety procedures involving any dissection activity. All students used dissecting scissors, not scalpels, and dissecting pins. The classroom was well ventilated and safety precautions in

the Lab were discussed with students at the beginning of the year and again prior to the dissection unit. Questions about safety were included in the first Chapter Test at the beginning of the year and a safety quiz was given as a reminder to all students of precautions needed before beginning the first of the four dissections.

The equipment used was washed and cleaned prior to each dissection as were the protective goggles. New vinyl or latex gloves were used for each of the four dissections. Clean-up consisted of students washing their hands prior to leaving the classroom at the end of each activity and placing their equipment, dissected organism and goggles in the appropriate area of the classroom. Should any injury have occurred, students would have immediately contacted the teacher and then sent to the office for any needed medical attention.

Data Collection and Analysis

Scoring was conducted after each dissection was completed on questions written by students and their answer to a chosen question. Two separate rubrics were used to evaluate both questions (Table 1) and answers (Table 2). The rubrics were researcher devised and contain a means by which student's written questions and their answers could be evaluated. The rubric for the written dissection questions (Table 1) began with a score of 1. This score reflected the written question as being a type of simple identification ("Where is this structure or organ found in the organism?"). The next level or score of 2 indicated another type of simple inquiry such as; "What does this organ or structure do?" The next two scoring levels, creative and critical inquiry, were established to determine whether the students had put thought and application of the concept into the

construction of their questions. A score of 3 indicated that the student was trying, but had not completely accomplished an application of adaptive evolution to their written question, which they could use as a direction for conducting their dissection. An example of a question receiving a score of 3 is the following; “What kind of circulatory system does the squid have?” The final score of 4, or critical inquiry, demonstrated that this question was a well written question with its focus adaptive evolution. The following written question is an example of a score of 4: “What consistency is the ink within the ink sac?” The question focused on the composition of this protective substance and how that aspect might improve survival. It is also an aspect of the dissection that can be tested.

Table 1. Sample rubric for student-generated science lab questions

Score	Description	Examples
1	Identification	Where is the gizzard? (location)
2	Simple Inquiry	What does the gizzard do? (function)
3	Creative Inquiry	Why is the earthworm’s gizzard so hard? (how does it relate to other organs and their function)
4	Critical Inquiry	How does the function of the gizzard help the earthworm survive? (How might this adaptation relate to the organisms survival?)

Table 2. Sample rubric for scoring answers to selected science lab question

Score	Evaluation	Explanation
1	Answer wrong	Discussion completely wrong
2	Answer partially Correct	Answer was attempted and has some correct components
3	Answer Correct	Answer correct regarding function or identification – No reference to adaptive evolution
4	Answer Correct as it pertains to adaptive evolution	Answer was correct and noted specific adaptive abilities of organism studied

The answer rubric used to score the responses to one of the three written student questions, was also divided into four scoring levels. A completely wrong answer received a score of 1, despite the fact that they did try to answer it and not leave the question blank. For example: a score of 1 was given to the answer written for the following question; “How many hearts does the earthworm have?” The answer was six, which is incorrect. A student response with a score of 2 from the Answer rubric showed that the answer was partially correctly. The response to “How many arms does it (squid) have?” was scored a 2. The student answered; “Usually six or more”.

With the final scores of 3 or 4, the researcher was looking for a correct answer and one which clearly demonstrated an understanding of the concept and the purpose of conducting the dissection. An answer, “It is part of the exoskeleton,” received a score of 3 as it was a correct response to the question: “Is the cephalothorax hard-shelled?”, but

did not go to the extent of discussing how the exoskeleton protected the cephalothorax. A score of 4 was given to a response written for the following question; “why do most crustaceans have eyes on stalks?” The answer written was: “Since they have a hard shell, it must be almost impossible to turn its head or turn around fast so it needs all around vision.” This answer is not only correct, but also implies very specific abilities allowed by the adaption to help with survival within the organism’s particular environment.

Results

Quantitative analysis: Scoring of questions

Each student composed three questions for each of the four dissections conducted. All three questions were scored using the rubric shown in Table 1 and the class mean score was calculated based on the scores of each of the three questions for all of the thirty-three students. Figure 1 displays the class mean question scores for each of the four dissections. Appendix C of this paper shows a table of the calculated mean scores for the three questions written by each of the students who participated in the assignment. Some students did not write all three questions and several students did not write any questions as results of choosing not to do so.

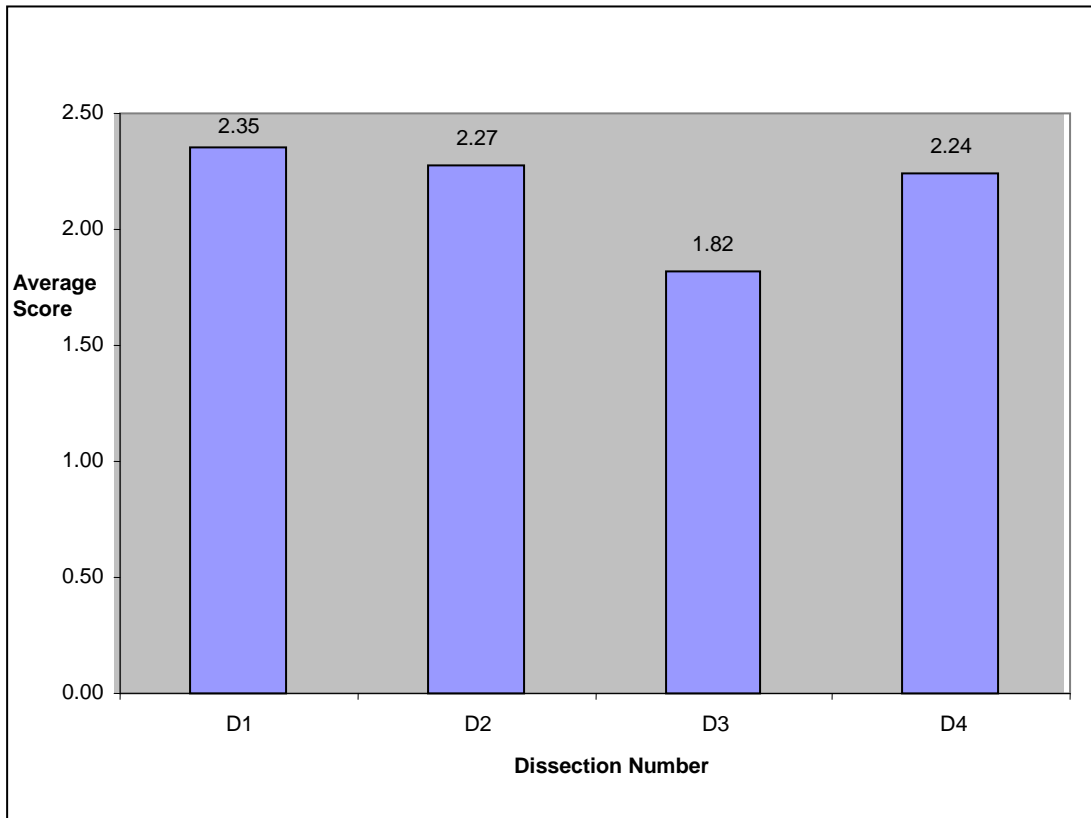


Figure 1. Mean scores for all questions written for all four dissections

There was no statistically significant difference, $t(32) = 0.71, p > 0.05$, between the means for all scientific questions written by the students for the first dissection ($M=2.35$) with a $SD = .70$ and the fourth dissection ($M=2.24$) with a $SD= 0.89$, with a mean difference of 0.11. Although this comparison did not show a significant improvement of scientific question writing skills over time, further analysis did demonstrate a positive change when analyzing each question selected by the individual student to be answered as part of their dissection lab. Figure 2 reflects the comparison between the first dissection (D1) to the last dissection (D4) of the mean question scores for one written question selected by each student to focus on during their dissection lab. The student's

chosen question came from the three written for each dissection at the time of the lab. This question was to be answered by the students with data and information gathered from the actual dissection as it was conducted. The student's answer was then recorded in their lab books and submitted for review by the researcher.

Since only 23 of the 33 students chose to answer one of their three questions for D4, the data was analyzed to compare the means for just those 23 students. This eliminated the impact of the scores of zero (as with Figure 1) as a result of absences or simply not following through to answer a particular question, after completing the lab. For this subset of 23 students, there was a significant difference for the D1 ($M=2.43$) with a SD of 1.03 and the D4 ($M=3.13$) with a SD of 1.01 and a *Mean Difference* of -0.69 (Figure 2), $t(22) = -2.44775$, $p < 0.05$.

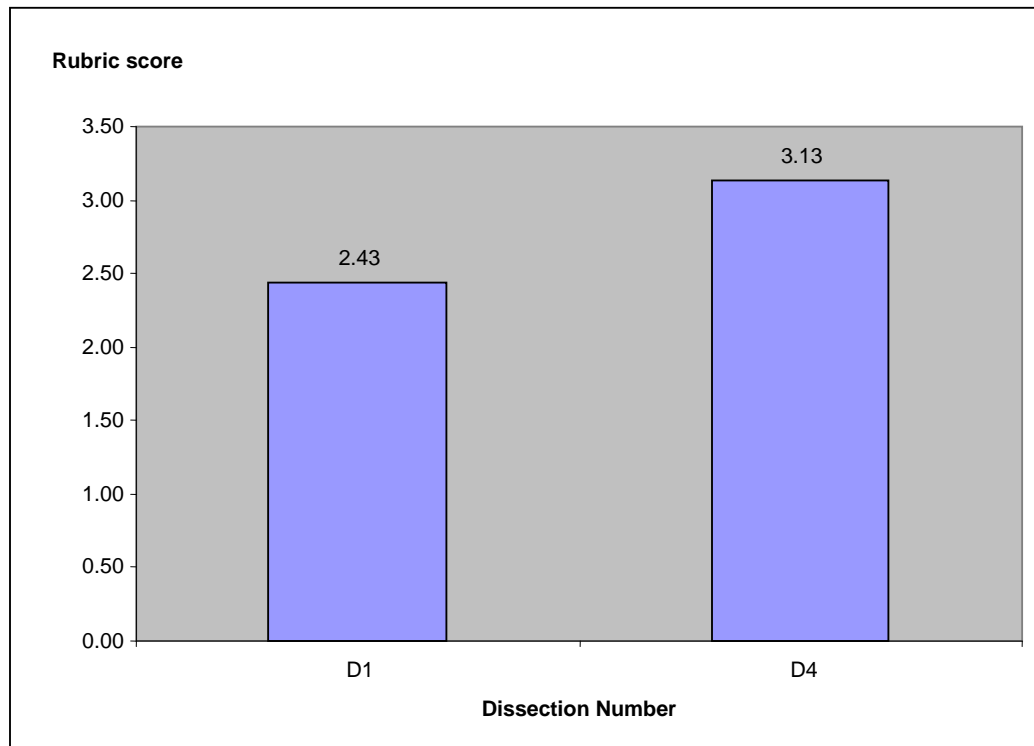


Figure 2. Comparison of mean scores for questions chosen by students for the first and last dissections.

Means for D1, D2, D3 and D4 student chosen questions are shown in Figure 3 (with zeros excluded). Means for D1 (2.43), D2 (3.03), D3 (3.00) and D4 (3.13) show a small but gradual improvement in question quality for the selected question that students used during their dissection to gather information and answered in the post-lab time period.

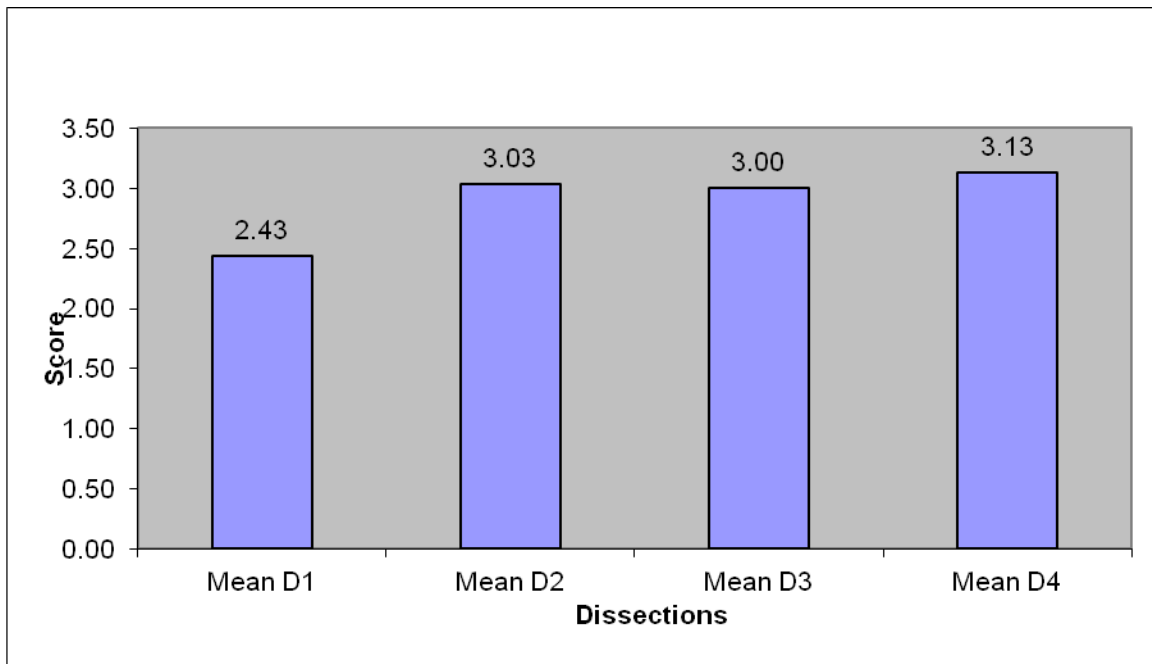


Figure 3. Mean scores for student chosen question for each of the four dissections

Quantitative analysis: Scoring of answers to student chosen questions

The scores on students' answers to their chosen questions also provided interesting results. The student answer scores improved slightly from the first dissection conducted to the last dissection (Figure 4). The mean answer scores were First ($M= 2.59$, $SD 0.91$) to Last ($M= 2.91$, $SD 0.89$) with a mean difference of -0.31 and a SD of difference of 0.93 . Although improvement was observed, it was not statistically significant $t(31) = -1.89$, $p > .05$ with $p = 0.066$. However, there is a trend at work and it is important that although $p > 0.05$ is the cutoff point, the test demonstrated a trend that might have been statistically significant, if the sample size was larger. Therefore, the hypothesis that student answer scores improved over time can be considered to be supported, despite the small sample size.

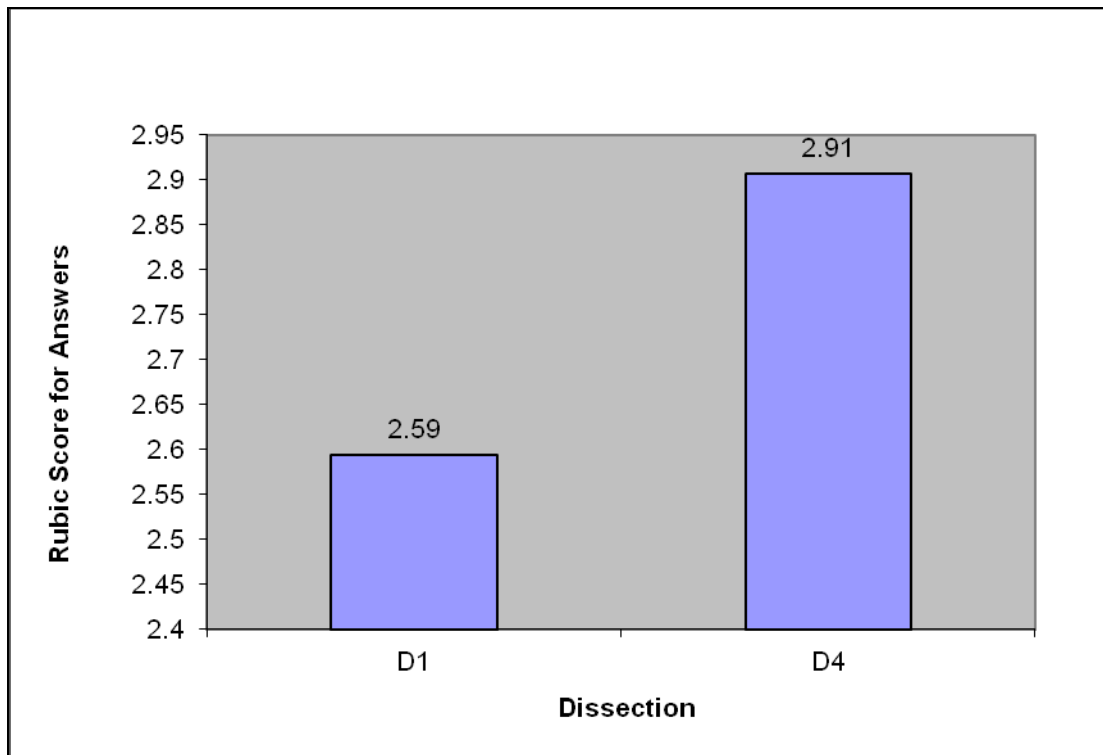


Figure 4. Mean student answer scores for D1 and D4

Quantitative analysis: Correlation

Another comparison was addressed as to whether students who asked higher quality questions (higher question score) tended to also answer questions more accurately (higher answer score). In the following Figures 5 through 8, a correlation for each dissection was used to analyze all four cases. The positive relationship seen in these figures indicates that students who ask better questions also answer their own questions better. The results were statistically significant for the first three dissections, but not for the fourth. The coefficient is the "slope" of the "best fit line" that is shown in Figures 5 - 8. These scatter plots are somewhat deceiving since multiple points may lie on top of one

another, so emphasis should be placed on the actual correlation value and p-value rather than the visual representations below.

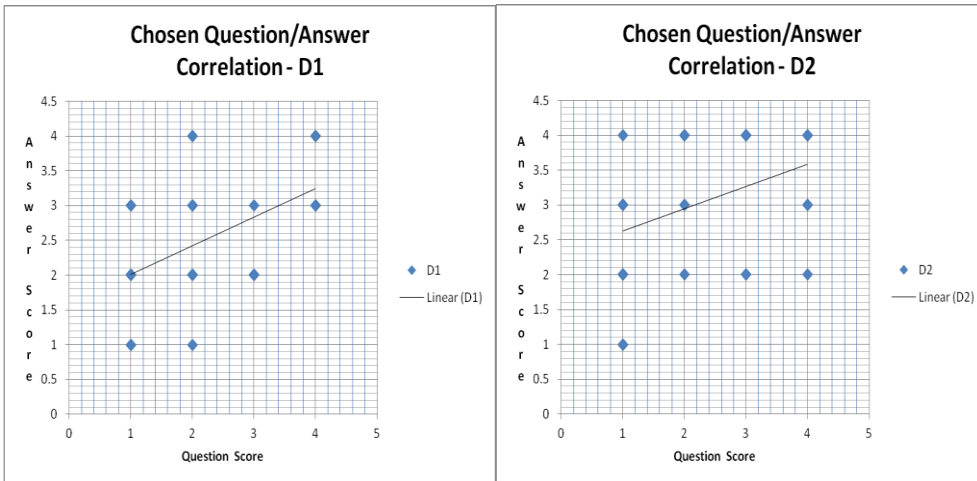


Figure 5. Earthworm Dissection

Figure 6. Squid Dissection

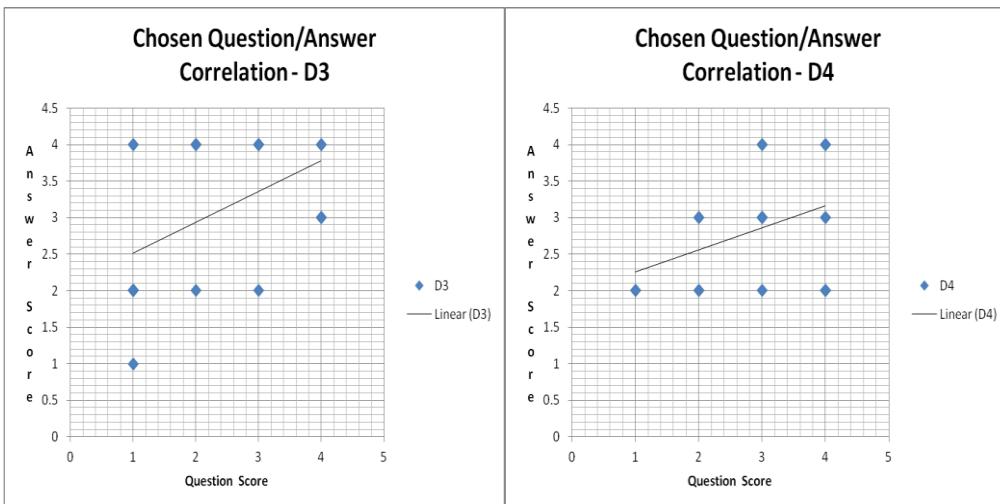


Figure 7. Crayfish Dissection

Figure 8. Frog Dissection

The correlation value between the questions chosen by students for the earthworm dissection (D1) and their answers was .50, which was statistically significant ($p < .05$). The correlation value for D2 (squid dissection) between questions and answers was .38, which was also statistically significant ($p < .05$). In addition, D3 (crayfish dissection) had a value of .49 which was significant as well at ($p < .05$). The final dissection for the frog (D4) did not have a correlation value which demonstrated significance at .37 with $p > .05$. Although very close, it was not significant.

Qualitative Results: A closer look at students' questions and answers

The ability of students to develop the process of critical thinking and knowledge application requires more than just rote memorization and the ability to get correct answers on lab reports or multiple choice questions. This research study did not use tests to evaluate student progress, but directed students through a question and answer process. It began with a research question written by the student and ended with an answer to that particular question after performing various dissection labs in an effort to make a connection between biological concepts and practical applications. It is that connection which was assessed, starting with a research question written by the student and ending with an answer to that particular question after performing various dissection labs.

Achievement levels of students (assigned by using the final grade received in the class) were used as a means of examining improvement of results from written questions and answers for a class of 33. Students were assigned an achievement level based on their final grade in the course as follows: High (A to A-); Above Average (B+ to B-); Average (C+ to C) and Below Average (C- and below). The data was analyzed based on

a rubric devised by the researcher to score both questions and answers. Table 3 provides examples of questions generated by students of various achievement levels along with the scores that were assigned based on the rubric. The “name” of the students listed on the table is a pseudonym and used only for the purpose of displaying samples of written questions. The Table demonstrates students within all ability levels wrote some very good questions, as well as some questions requiring a great deal of improvement. Therefore, not just the high achieving students created critical inquiry questions, but also some of the students that were not as strong academically in the subject of science.

Table 3. Overall Sample Student Questions and their ratings

Name	Achievement level in the course	Dissection Number	Written Student Questions	Question Score
Dean	high	#1 Earthworm	Why must the intestine be so large?	4
George	above average	#2 Squid	Why do squids have specific number of arms?	4
Adam	average	#3 Crayfish	Why might it have four antennae?	4
Dan	below average	#4 Frog	Are the hearts on a multiple lines like a parallel circuit or if one heart fail, it dies?	4
Mary	high	#1 Earthworm	How does the earthworm use its anus?	3
Samantha	above average	#2 Squid	How do squids move from place to place?	3
Luke	average	#3 Crayfish	How thick is its shell?	3
Dan	below average	#4 Frog	How different is their reproductive system from ours?	3
John	high	#1 Earthworm	What is the gizzard?	2
Karen	above average	#2 Squid	How do suckers help the organism?	2
Faith	average	#3 Crayfish	Are all of its outer body parts hard?	2
Amy	below average	#4 Frog	How does a frog function?	2
Mary	high	#1 Earthworm	What do earthworms eat?	1
Frank	above average	#2 Squid	How many fins are there?	1
Paul	average	#3 Crayfish	How long is its antennae?	1
Francis	below average	#4 Frog	How are frogs and humans alive?	1

Evaluation criteria for the questions, was shown previously in Table 1 and restated in Table 4 for discussion.

Table 4. Question Rubric

Score	Evaluation
1	Identification
2	Simple Inquiry (function)
3	Creative Inquiry
4	Critical Inquiry

The scores for the student questions assessed whether the questions incorporated an understanding of the concept of adaptive evolution. A score of “1” or “2” for a particular question demonstrated that the student focused on only the identity or function of a particular structure, rather than how that structure affected the organism’s ability to successfully adapt to their environment. A question given a score of “3” indicated that the student’s question was directed toward trying to understanding the concept of adaptive evolution as discussed in class. Finally, a score of “4” demonstrated understanding of the student within the structure of their question. The composition of these questions indicated the student was trying to analyze how the physical makeup of an organism or its adaptations related to its habitat, which ultimately contributed to the organism’s survival and ability to reproduce or natural selection.

Using achievement levels for the biology course, samples of questions could also be reviewed and compared. In a general overview of the data, the students with a High or Above Average achievement level tended to have questions which were considered to be critical thinking questions in regards to adaptive biology. However, as can be seen in

Table 3, not all critical thinking questions were written by High Achieving students, as this table includes examples of questions at all four scoring levels written by students at all four achievement levels. Table 3 gives specific examples of excellent questions which were generated by students from all achievement levels.

While examining class averages is informative, taking a look at all of the questions and answers for selected individual students allows for a glimpse into how students think, as well as what they might gain from activities such as the ones in this study. Tables 5 and 6 contain samples of both questions and answers from one High Achieving student and one Low Achieving student who participated in the study. The tables provide an opportunity for consideration of both questions and answer scores.

Table 5. Student 32/ High Achievement Level: Written Student Questions and Answers

Dissection	Question	Question Score	Question Chosen	Answer	Answer Score
Earthworm	1 – What is the purpose of the gizzard?	1	No	-	-
Earthworm	2- Are the hearts circular and surround the esophagus?	4	No	-	-
Earthworm	3- How do the earthworms breathe while underground?	4	Yes	Earthworms breath through their skin, using moisture to help the oxygen diffuse through the tissues	4
Squid	1- Is your squid a male or female?	2	No	-	-
Squid	2 – Can the pen be easily removed?	1	No	-	-
Squid	3 – What consistency is the ink within the sac?	4	Yes	The ink has a somewhat lumpy texture, not unlike mud.	4
Crayfish	1- How often do crayfish molt?	3	No	-	-
Crayfish	2 – Can Crayfish swim?	1	No	-	-
Crayfish	3 - Can chelipeds regenerate?	4	Yes	Yes, after being removed, or destroyed, the chelipeds will often regenerate.	4
Frog	1- Is our frog male or female?	1	Yes	Our frog is obviously male, as indicated by the testes.	2
Frog	2- Do the frog’s muscles provide a more difficult thing to cut?	3	No	-	-
Frog	3 – Can we tell how old our frog is?	4	No	-	-

Table 5 shows well-focused questions and answers of a student in the high achievement level. The data demonstrates that this student had an understanding of the

concept of adaptive evolution and attempted to author questions which pertained to the adaptive capabilities of the organism and how that adaptation improved the organism's survival capabilities. The questions written were not about identification or function, but demonstrated critical thinking about how the organism used those adaptations to successfully live in their particular environment long enough to survive to reproduce.

An example of this student's thought process was shown by the question posed regarding the consistency of the squid ink which can be seen on Table 5. The question written did not ask what the name of the organ was that produced ink or what the ink was used for, but rather why the ink had a particular appearance. The question and answer was not limited to the color, but rather consistency. The student's answer discussed the thickness or texture of the ink which may be beneficial to the squid's protection. The significance of this question and answer lies in the fact that it could lead to more probing questions that the student might be interested in exploring with research or further experimentation. It also could trigger questions as to why this squid still had ink, when the majority of other squids being dissected at the time, had none. Often after a dissection, many of the students discussed with the researcher the answers to their questions to find out if they were correct. This often lead to very interesting discussions within the class, as students speculated on whether the questions and answers written were appropriate.

For comparison, Table 6 shows the questions and answers written by a student evaluated as "below average" for Achievement level based on their grade in the class. This student had trouble with formulating focused questions that could be answered as

the student examined the organism. The reason for this could be due to absences prior to the class discussion regarding how to write questions pertaining to the concept of adaptive evolution or perhaps due to a lack of understanding regarding the concept and how physical traits help to promote survival and successful reproduction. The student wrote questions that were limited to identification or failed to complete the assignment by writing any question at all. Some examples of such questions were: "How does a crayfish function?" or "Does the earthworm have more than one heart?" The student may have been confused as to the assignment, but the questions are either very broad and out of the scope of the lab or answered very simply with a "Yes" or "No".

Table 6. Student 19/Below Average Achievement Level: Written Student Questions and Answers

Dissection	Question	Question Score	Question Chosen	Answer	Answer Score
Earthworm	Why is there organs different than another one?	1	no	-	-
Earthworm	Does the earthworm have more than one heart?	1	yes	Yes, it had more than one heart.	2
Earthworm	Does the earthworm survive different?	3	no	-	-
Squid	Does the squid have many hearts?	1	yes	Yes, it has more than one heart.	1
Squid	If so, how many hears does the squid have	1	no	-	-
Squid	Was this squid hard to observe?	1	no	-	-
Crayfish	No question written	0	-	-	-
Crayfish	No question written	0	-	-	-
Crayfish	How does the crayfish function	2	no	-	-
Frog	How does the frog function?	2	no	-	-
Frog	No question written	0	-	-	-
Frog	No Question written	0	-	-	-

Unplanned Survey

The majority of students participating in this study thought that developing their own questions challenged them to find answers, more so than using a textbook or diagram. After the conclusion of the four dissections, an informal survey not included in the IRB-approved experimental design was given to all 33 students to assess their opinion on their performance of dissections based on the generation of their own questions. Students felt that writing questions generally was easy, but qualified that answer by stating “it depended

on what lab we were doing and on the complexity of the organism. For example, since the earthworm was so small and less complex, it was hard to find questions about its makeup and functions.” When asked if the dissections helped the student to understand the organism and how it lived within its environment, one student responded: “Yes, even though the organisms had similar organs and body functions, they were each unique and were specially adapted to fit that organism’s lifestyle. They helped me understand the importance of adaptations and what each animal does to meet their needs that make them suitable for the environment.” Another student answered, “Yes, because when you open an organism, you can really tell every part of it and naturally want to know why it’s there.”

Many students noted that the importance of the experience was its connection to the real world and the ability to examine an organism extensively: “Looking inside the organism you can see and understand all the reasons for that certain organism to have those organs and the reason why they are in a certain place. You can also understand why their skin is the way it is either for defense or just because it is a way for the organism to stay moist.” Another student answered: “Seeing everything in person really helped me understand the organism more. Diagrams don’t really give you an idea on what everything is really like. This was a fun way to explore and enjoy science.”

Students were also asked to assess their own ability to write questions that critically examined the adaptive ability of the organisms dissected. Some students answered that writing the questions was both easy and hard to do. In fact, “some of the time, I couldn’t answer my questions. But, on other occasions I found it rather easy to do.” Many students admitted it was easy to fall into the traditional format of writing questions to “identifying

parts and how that certain part helps them to survive.” Some discussed that it was easy to write the questions to look at adaptation because of “all the information we needed was already written and discussed with us” before the dissections were performed. Another student responded that it was hard to write inquiry questions “because for a few (labs) I didn’t have very much knowledge that related to the questions I had written.” A student that described writing the questions as easy wrote that “we had plenty of resources. The resources allowed us to read the information to find our answers or to ask questions of Mrs. Reed.”

Conclusion

The National Science Education Standards (NSES) state that teachers of science must make decisions: “such as when to change the direction of a discussion, how to engage a particular student, when to let a student pursue a particular interest” (NRC 1996, p. 33). Within this study, students were allowed to identify their own goals in the form of questions to be answered after performing a dissection and thus guiding their own learning.

The initial results based on the evaluation of all scientific questions written by the thirty-three students participating in this study demonstrated no statistically significant difference between the first and last dissection. Although this study did not demonstrate significant results to answer the original research question in terms of improvement in scientific questioning and answering skills over time; the study did demonstrate with the

use of statistical correlation for three of the four dissections, that students could learn by becoming more involved in the scientific process, when they write their own questions.

The purpose of this study was to answer the following research question: Is it possible to improve student scientific writing skills beginning with their ability to formulate questions when a limited inquiry-based format for animal dissection labs is used? Unfortunately, data from the study did not support this question as the results were shown to be statistically insignificant. A t-test for Dissection 1 question score mean compared to the result for the question score mean of Dissection 4 (for each of my 33 students) Did not display a positive improvement over time of student question writing skills and in fact, the scores on the written questions appeared to get worse. It is important to note, however, that scores of zero were included in these means (a zero was assigned when a student did not write a question).

Considering only Figure 1, the question writing skills did not seem to get better over time when comparing the means calculated for the three questions written by each student for the four dissections. The good news, however, is revealed when comparing the single question picked by each student (of the three written for D1 and D4) to be answered after the dissection was completed. The hypothesis written for this project was not formulated to examine the scores on students' answers to their chosen questions as a specific aspect of the research, but when examining the data, this secondary question regarding comparison of the chosen question to answer scores became evident. The hypothesis that students would improve their answer scores as well as their science writing skill of question composition was not statistically supported, but a trend does

seem to exist. One reason for the lack of supportive results perhaps was due to the small sample size. Nevertheless, there was an obvious trend that did present itself, as the chosen question and answer scores were analyzed.

While the difference between Dissection 1 and Dissection 4 was not quantitatively supported, numerous students who participated in this study and completed a written survey (Results section: Unplanned Survey) verbally declared that animal dissection helped with their understanding of adaptive evolution. Many students were also of the opinion that the repeated practice of writing scientific questions with each dissection promoted good question formation and helped them understand the subject or concept studied. When the core premise of an activity includes the need for learning to be centered on the questions created by the student and not the teacher, students seem to be more engaged and involved in their own learning experience.

Therefore, inquiry-based pedagogy could be a very useful tool for maximizing learning in the classroom, especially in regards to the biological concepts such as adaptive evolution and scientific question writing skills. When students focus on an organism's physical adaptations (in relation to the challenges within its environment) and not simply the identification of anatomical structures or their functions, it can be hypothesized that there will be an improvement in their scientific question writing skills with continuous practice using a structured inquiry-based format throughout a series of animal dissections.

An impressive difference between the means was shown when the scores for each student's chosen question for all four dissections were recorded and analyzed; mean

scores were significantly higher for dissection 4 than for dissection 1 (Figures 2 and 3). It appears that many students challenged their knowledge of the concept of adaptive biology by choosing their hardest question to answer, after completing a dissection. The orientation toward asking questions within a limited inquiry-based format allows students to reveal their level of understanding about the concept and encourages them to generate their own interest in that topic.

This study presents evidence that middle school students can handle a structured inquiry format for experiments, especially dissection labs. The qualitative results for this study presented a number of questions and answers which clearly demonstrated students moving beyond the traditional format of identification and function in regards to dissection labs. The majority of the students who participated in this study were able to write their own questions pertaining to the concept of adaptive evolution without any direction from the teacher. They also answered their own questions by examination of the specimens without teacher's assistance, thus providing evidence as to their ability to follow through with a structured-inquiry format.

In order for students to create questions that demonstrate critical thinking skills, they need opportunities to practice those skills, both verbally and through writing. However, posing questions is only part of the scientific process and the beginning of scientific inquiry in the classroom. As this study demonstrated, there are many problems that confront teachers when trying to implement a curriculum centered on question formation.

Limitations

There may have been many reasons for the lack of significant results for this study as there were a number of limitations that affected the process. The main reason could be time constraints within the class period causing students to focus the majority of their efforts on writing one "good" question that they were interested in and then rushing to write two other simpler questions, just to meet the requirement before the end of the period. Students were given about 15 - 20 minutes at the end of Day One of the procedure to generate their own questions, and were not allowed to take the lab books home. This may not have been enough time, so they worked very hard on just one question and did less work on the other two when they realized their time was so limited.

Another limitation is the small sample size (N=33) for the study. The results for the original research question did not show a trend for improvement as the mean differences were not statistically significant. However, the use of correlation values to explore the relationship between question scores and answer scores did show a positive relationship for three of the dissections, except the last. Further research using a larger sample size might generate more statistically significant results. Another impact to the sample size was the scoring of a zero to those students that did not write all three questions as well as certain students which did not write any questions based on an absence or simply choosing not to do so. Therefore, those student scores on the written questions appeared to get worse and not improve over time, due to the small sample size and the effect of absences and neglect to finish the assignment.

Implications for teachers

There are several challenges which still remain today, even though there is a great emphasis on implementing inquiry based science education. Many teachers, whether elementary middle or high school, are not comfortable with an open or even a limited inquiry format for experiments and prefer written procedures and expected results to be available to them for direction, support and distribution to their students. Another reason for teachers to hesitate to use this approach to teaching science is due to the fact that they were not taught in this way during their preparation to become science educators (Yager & Akcay, 2010). Several elementary teachers have confided to me that it was difficult to teach the material even without an inquiry format, as they felt uncomfortable with the subject matter. One teacher lamented that “the students I had when I was teaching a unit on electricity still to this day must be confused as I was ill prepared to teach that unit”. Another teacher felt her primary responsibility was to make sure the elementary students she taught could read, write and do math “otherwise how could they possibility do science”. As a result the other subject areas received more time and attention then the science curriculum. To establish a science inquiry format (even limited inquiry pedagogy) within classrooms in which teachers already feel uncomfortable with the subject matter or consider other subject areas to be of a higher priority is a limitation to implementing a student question based science curriculum.

Also, included in the limitation to implementing inquiry-based science education are the parents of both elementary and secondary students. In my teaching experience, I have had several parents rejecting this non-traditional format because there are no clear

cut answers to be found in a textbook or even on the internet. They are uncomfortable with the format and convey that to their child or me, as a result of trying to assist the student with science homework.

Assessment is another limitation to implementation of inquiry-based pedagogy. Teachers struggle to develop ways to evaluate students who participate in inquiry-based instruction. The challenge is to be able to assess for understanding, while trying to include all features of inquiry, not just evaluating knowledge gained which can be done by using standardized tests. Because the process is based on what is important to the students and the knowledge they possess prior to beginning an inquiry investigation, assessment requires the teacher to develop an unconventional way to assess each student's effective way of learning based on that student's ability to alter prior knowledge, as well as the knowledge gained. In this research, a rubric was developed to ascertain the level of critical thinking involved in the formulation of questions that dealt with dissections of four organisms.

Finally, although the class size of 33 was a limitation for statistical significance, the number of thirty-three students in a science classroom can in itself be a limitation. Having a large class size such as 30 to 35 middle or high school students in a science lab at one time can create difficulties not only with trying to implement an inquiry format, but with monitoring the student's safety and progress. A teacher would need to have exceptional control over the class or enough help that the students stay on task and are able to ask questions of the teacher or assistants in order to progress through the experiment, let alone develop their own inquiry question and procedure.

Therefore, while statistically significant differences were not seen in this study, numerous students who participated verbally declared that animal dissection can be a form of active learning which helped with their understanding of adaptive evolution. Many students were also of the opinion that the repeated practice of writing scientific questions with each dissection, promoted good scientific question formation. When the core premise of an activity includes the need for learning to be centered on the questions created by the student and not the teacher, students seem to be more engaged and involved in their own learning experience. This research based on a small sample provides support for use of a new type of dissection activity in middle school classrooms – one based on both the interests of and curiosity of students as motivators of learning.

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Appendix A: Cover letter for parents

March 26, 2010

Dear Parents,

This spring, the Biology students will be conducting four dissections of various invertebrate and vertebrate organisms. Although this is a normal science activity, their participation this year will be part of a study I am conducting on scientific question writing skills and how they can be improved through inquiry-based dissection activities for my Master's Degree in Biology through Point Loma Nazarene University. Your student's confidentiality will be maintained throughout this study and their participation is voluntary.

If you have any concerns regarding your student's participation in this study, contact me through the school office or by email at bioteach_75@yahoo.com. Please return the attached form with your signature, if you give permission for your child to participate in the study.

Date _____

Child's name _____

Parent/Guardian signature _____

Thank you,

Mrs. Reed

Appendix B: Principal's letter of approval

March 26, 2010

Attention IRB Committee,

As principal of Nazareth School, I have discussed with Mrs. Reed the study which she is conducting on science writing skills. She is conducting this study as part of a requirement for completion of a Master's of Science in Biology. I have given her permission to do so. Please contact me through the school office if you have any questions or concerns. I can be reached at (619)641-7987.

Sincerely,

Dr. Colleen Mauricio

Principal

Appendix C: Table of the mean scores

Table of the mean Scores for each group of three questions written by 33 students prior to conducting four different animal dissections.

Student ID	D1	D2	D3	D4
1	2.33	2.00	1.33	2.67
2	2.00	3.00	1.67	1.67
3	2.33	2.33	2.33	2.67
4	3.33	0.67	2.67	2.67
5	2.67	3.33	2.33	2.67
6	3.00	2.67	1.33	3.00
7	2.67	3.33	1.00	1.67
8	1.67	3.00	2.00	0.00
9	3.00	2.33	3.00	3.67
10	2.33	2.00	3.67	2.33
11	3.67	3.33	3.00	3.33
12	2.67	1.33	0.00	0.67
13	2.00	2.00	1.33	3.33
14	3.00	3.67	3.67	2.33
15	1.67	2.33	1.67	1.33
16	3.00	2.33	2.67	3.00
17	2.33	2.33	1.00	2.33
18	3.00	3.00	1.33	2.33
19	1.67	1.00	0.67	0.67
20	1.67	3.67	0.00	2.67
21	2.00	1.33	1.67	1.00
22	0.00	2.33	2.00	2.33
23	2.67	3.00	2.33	2.33
24	2.00	2.00	0.00	2.00
25	2.00	2.00	1.67	2.67
26	3.00	1.67	2.33	3.00
27	1.00	1.00	1.00	2.00
28	2.33	1.67	2.67	1.67
29	2.33	1.67	1.00	1.00
30	2.67	2.00	3.00	2.67
31	2.67	1.67	2.00	2.33
32	2.67	3.33	2.00	4.00
33	2.33	1.67	1.67	2.00
Avg.	2.35	2.27	1.82	2.24