EFFECTS OF THE 5E LEARNING CYCLE ON STUDENT CONTENT COMPREHENSION AND SCIENTIFIC LITERACY

by

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A professional paper submitted in partial fulfillment of the requirements for the degree of Master of Science in Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2012
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Charlotte L. Hagerman

July 2012
TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND .................................................................1
CONCEPTUAL FRAMEWORK .................................................................................3
METHODOLOGY .....................................................................................................11
DATA AND ANALYSIS ..........................................................................................17
INTERPRETATION AND CONCLUSION ...............................................................35
VALUE .....................................................................................................................36
REFERENCES CITED ..............................................................................................39
APPENDICES ..........................................................................................................41

APPENDIX A: Student Perception of Teaching Methods Survey ..................42
APPENDIX B: Administrator Exemption Regarding Informed Consent ..........44
APPENDIX C: Previous Science Experiences Survey .....................................46
APPENDIX D: Student “Hands-on” Science Activities Survey .....................48
APPENDIX E: Rubric for Engagement in Essential Features of Inquiry .........50
APPENDIX F: Scoring Guide for Laboratory Report ........................................52
APPENDIX G: Assessment on Team’s Performance .......................................56
APPENDIX H: Journal Entry Prompts .................................................................58
APPENDIX I: Student Perceptions of Mental Activities .................................60
APPENDIX J: Student Perceptions of Activities Contributions to Growth ......62
APPENDIX K: Post-Activity Interview Questions .............................................64
iv

LIST OF TABLES

1. 5E Learning Cycle: Purpose and Activities .................................................................10
2. Data Collection Methods .............................................................................................16
3. Summary of Student Scores on Lab Report.................................................................27
LIST OF FIGURES

1. Student Responses Regarding Time Spent Following Given Protocol .......................18
2. Student Control Over Experimental Design .................................................................18
3. Comparison of Passing Grades Between Boys and Girls for Lab Assessments ..........20
4. Comparison of Passing Grades Between Boys and Girls for Practical Application Assessments .................................................................................................................................20
5. Student Perception of Mental Activities Emphasized by the 5E Learning Cycle ......21
6. Student Scores on Procedure Section of Laboratory Write-up ................................25
7. Student Scores for Data/Observation Section in Lab Report ....................................25
8. Student Scores for Essential Features of Inquiry .......................................................30
9. Students Perceptions of the 5E Learning Cycle Contributions to Growth ............32
ABSTRACT

In this investigation the 5E learning cycle was implemented as the primary teaching method, with the purpose of improving student’s content comprehension and scientific literacy skills. The steps of the 5E learning cycle were continuously carried out using a wide variety of assessments. Though content comprehension did not increase dramatically, students did show marked improvement in their scientific literacy and ability to think critically.
INTRODUCTION AND BACKGROUND

I have taught 9th-12th grade at Round Valley High School in Eagar, Arizona for the past five years. This is the only high school in a small community composed of 2 connected towns and a combined population of approximately 6,000 people (http://www.apachecounty.com/index.htm). Our high school has about 320 students. Some of these students are bused in from outlying communities 20 to 30 miles distant. The school has a large Hispanic population, most of who are second language learners and are not proficient in the English language. The students in my classes come from families ranging from low to lower-middle income level, the median income of households being $30,769 (http://www.somplyhired.com/a/local-jobs/city/l-Springerville,+AZ).

Though many students have a high academic ability, they have not been encouraged to excel and are content to simply get by. Through multiple conversations with colleagues and students, I have learned that academic success is not a priority. Roughly 84% of students interviewed did not plan on attending college. Instead, many of them expressed the desire to remain in the community and apply for a job at the power plant, the area’s largest employer (http://www.apachecounty.com/Downloads/Eager%20and%20Springerville.pdf). The overall student attitude is toward mediocrity: do only enough to pass a class to avoid re-taking it the following year.

Changing this widespread, apathetic student mind-set has become a primary focus of our science department. The chair of our division has asked us to brainstorm ideas that
will effectively engage the students in their own learning. He challenged the teachers to find ways to focus on scientific process, rather than on memorization of content, in order to make science more meaningful for students.

In response to this request, I focused on analyzing my teaching strategies. Traditionally, I have relied on instructional methods that include lecture, hands on activities, and cookbook style labs. My lessons have primarily been teacher-centered, with students playing an inactive learning role as recipients of disseminated knowledge. As a result, they have been deprived of activities that would effectively foster the development of higher-order thinking skills. Personal reflection has assisted my understanding as to why many of my students lack the conceptual understanding needed to apply content in a way that will further their understanding. Though proficient in memorizing content material, the majority of my students have been deficient in their abilities to expand their knowledge for use in real-life situations in a way that will allow them to effectively participate in the scientific process.

My project sought to address the concerns of my students, as well as the goals of my department chair, through the application of activities that focus on the development of critical thinking and process skills by encouraging inquiry on the part of the student. After researching the different teaching methods and ideologies, I decided to focus this study on specific aspects addressed by the constructivist view of teaching and learning. I believed the implementation of the 5E learning cycle, a method which ties into the constructivist views of teaching, would be an ideal way to address the criteria set forth by my department chair, while simultaneously providing a more effective learning environment for my students.
The primary purpose of this project was to discover if the use of the 5E instructional model in a sophomore and junior level biology course would increase student understanding of science concepts and processes, fostering application to real-life situations. The secondary focus of my research was to evaluate the student’s scientific literacy skills, assessing if the use of this model would help them to become more proficient in expressing their ideas through conversation and writing.

CONCEPTUAL FRAMEWORK

The term constructivism embodies the idea that acquisition of knowledge is not a passive process accomplished through the transmission of information from one individual to another. Rather, the conversion of information and experiences into knowledge and comprehension is an ongoing process of assimilation and accommodation in the mind of the individual; it occurs through interpretation and communication with others (Bybee, 2002; Cobern, 1991; Llewellyn, 2005; Posner, Strike, Hewson, & Gertzog, 1982; Solomon, 1987; Tobin, 1993). Constructivist advocates function with the understanding that the learner uses links between new and previously stored knowledge within the brain to create knowledge. Constructivist thinkers indicate that learning is an active process that is built on previous understandings and is the interaction of ideas and processes. They also emphasize that learning is enriched when imbedded in familiar contexts and involve complex problems with multiple solutions (Bybee, 2002). Another essential point of constructivism is that learning is dependent upon language and communication, thus it is enhanced when students engage in discussions of the ideas and processes they encounter (Bybee, 2002; Yager, 1991). When performed in a science classroom, this ability becomes known as scientific literacy.
Attempts to define scientific literacy by a variety of individual groups with differing social and economic agendas has led to uncertainty about its true meaning and how it should be addressed in the science curriculum (DeBoer, 2000; Millar, 2006; Murcia, 2009). Since its introduction in 1958 (DeBoer, 2000), scientific literacy has endured shifting educational themes, yet it has now become one of the main learning goals in science education and is a requirement of the *National Science Education Standards* (National Research Council, 1996).

Most recently, scientific literacy has been defined as a social process, not only requiring opportunities for students to read and write but also to communicate with others about their ideas. This process encourages a richer understanding of the content as well as an increased ability to solve personal and societal problems (Krajcik & Sutherland 2010; Lloyd, 1990). In order to achieve the goal of promoting scientific literacy in our students, it has been suggested that the most effective methods of teaching are those that are inquiry based. This is due to the fact that these instructional features are adept at promoting the student’s ability to read, write and communicate about science (Krajcik & Sutherland, 2010).

Students enter the classroom with previous conceptions that have been constructed through the integration of prior experiences, social and economic class, religion, geography, ethnicity and language. Individuals depend upon these understandings to make sense of the world around them (Bybee, 2002; Cobern, 1991; Llewellyn, 2005; Tobin, 1993; Yager, 1991). These preconceptions are an important factor in how students interpret new information. The teaching methods implemented will play a major role in determining how new situations will be interpreted by the
student and if these situations will be accepted or ignored by the individual. Thus, the constructivist teacher provides opportunities for students to engage in self-organization and reorganization of their understandings through comprehension, synthesis, and eventual application (Yager, 1991).

Throughout the world, teachers have conventionally incorporated teaching methods that stem from the behaviorist-positivist tradition, relying primarily on the inform-verify-practice procedure (Marek & Cavailo, 1997). This model usually commences with the delivery of science concepts and relevant terminology through lecture, television, computers or other forms of media. Following this, the students are required to show the validity of what the teacher has covered in lecture by completing an experiment, in which there is no inquiry and the outcome is known before the activity is performed. Finally, the students complete their learning by solving problems, answering questions, taking quizzes or engaging in additional readings (Marek & Cavailo, 1997).

There are several drawbacks to this form of teaching, the first being the absence of real experiences for students to coordinate into their existing schemata. Furthermore, students experience difficulty understanding the material. This is due to the assumption that there is no need for the students to experience the content prior to the lecture, and therefore the language has not been made meaningful. Another blatant deficiency is that the practice portion of this teaching method rarely includes opportunities for students to increase their experiences using apparatus’ or materials. Instead, the activities incorporated remain on a more verbal level. The activities integrated in this form of teaching foster the misconception that science is complete and that every procedure performed has an expected outcome. This tradition of teaching, in which learning is
viewed as receiving and storing of knowledge by students, inhibits the development of higher-order cognitive skills (Marek & Cavailo, 1997; Tobin, 1993).

In light of these understandings, constructivist teachers deviate from the traditional behaviorist-positivist tradition of teaching. Instead, they focus on creating a learning environment where conceptual change can take place. Specifically, this is an environment which makes use of students’ prior knowledge, giving them an opportunity to recognize their conceptions, evaluate them, and then determine the importance of reconstructing those conceptions by reconciling prior knowledge with new knowledge (Hewson & Hewson, 1983; Llewellyn, 2005).

In order to accomplish this goal, constructivist teachers select teaching strategies that will create essential learning conditions. These conditions include the students’ dissatisfaction with their existing conceptions, in addition to the new scientific conception being intelligible, plausible and useful in a variety of new situations (Bybee, 2002; Cobern, 1991; Llewellyn, 2005; Posner et al., 1982). An effective constructivist teacher will foster conceptual learning by providing opportunities for their students to acquire, integrate and apply their new knowledge, while at the same time using a combination of techniques that encourage reflection through communication, reading, writing and doing science (Bybee, 2002; Tobin, 1993).

Addressing these issues requires science teachers to first identify the ideas that are most important for students to learn. Following this, they need to decide how best to teach those ideas, given the difference between what students currently know and understand and the accepted scientific explanations (Bybee, 2002). To accomplish this
goal, instruction should be designed to assist students in connecting new knowledge to bigger ideas, while at the same time addressing their prior knowledge to help them reconstruct the information within their own minds, so they can take control of their own learning (Taylor, Van Scotter & Coulson, 2007). Lessons need to provide students with the opportunity to continue their inquiry by affixing their learning to questions that are applicable to their own lives, as well as connecting them to a variety of situations. In addition, the teaching methods chosen by teachers need to encourage students to use science ideas and engage in scientific dialogue (Krajcik & Sutherland, 2010). The 5E learning cycle is a constructivist teaching model that incorporates effective hands-on, minds-on, inquiry based scientific pedagogy (Balci, Cakiroglus & Teddayas, 2005; Liu, Peng, Wu, & Lin, 2009).

Unlike traditional teaching methods in which direct instruction remains the dominant method for delivering information, the 5E learning cycle moves science teaching from a simple hands-on, discovery approach to creating an environment where students can explore new concepts, reevaluate their past experiences and assimilate or accommodate their new experiences and concepts into their existing schemata (Balci et al., 2005; Settlage, 1998). The 5E learning cycle is also instrumental in promoting an environment of scientific inquiry, which is a requirement of the National Science Education Standards (National Research Council, 1996). As described by Llewellyn (2005), scientific inquiry provides a way to develop students’ habits of mind. More specifically, this addresses skills of higher-order thinking, communication and decision-making, problem-solving, and critical and scientific reasoning, as well as the development of a student’s metacognition.
First created by Robert Karplus in the late 1950’s (Liu et al., 2009), the 5E learning cycle uses a specific sequence of three phases of instruction designed to promote conceptual change. The first phase of instruction is exploration in which students experience the desired concept. Following this, the students engage in conceptual invention where the concept is extrapolated from the data obtained during the exploration. Finally, students are given the opportunity to apply the concept by investigating its usefulness and application (Abraham, 1997; Tobin, 1993). The 5E learning cycle accomplishes these phases in five specific steps summarized below.

The first phase, *engagement*, allows the teacher to assess the student’s current understandings as well as their misconceptions through the use of attention-grabbing demonstrations or discrepant events. The intention of these activities is to introduce the purpose of the lesson while setting the stage for inquiry by creating cognitive dissension in the mind of the student.

Following the first phase of the cycle, students begin the *exploration* phase in which they are given a chance to raise questions, develop hypotheses and work with each other as they collect evidence, record data and share observations. This time encourages students to build on common experiences through inquiry-based labs or teacher-based inquiries.

During the *explanation* phase, the teacher adopts a more central role while discussing information and explaining the concepts associated with the student’s exploration. Lessons during this phase introduce the students to the scientific terminology that allows them to describe their experiences, as well as provide the
opportunity for students to link their experiences to the scientific concepts being explored.

The fourth phase in the 5E learning cycle is for *elaboration*. The central purpose of this stage is for the teacher to reinforce the intended concepts by engaging the students in activities that will allow them to extend and apply the evidence to new and real-world situations. Students are encouraged to construct valid ideas about the phenomena being studied through modification of their prior conceptions to include the new knowledge that they have gained through their explorations.

The final stage of the learning cycle is *evaluation*. This phase uses formative or summative assessments to bring closure to the lesson and determine the students’ current level of understanding. The evaluations provided during this phase will engage the students in a new activity that requires them to answer higher-order questions helping them to analyze their ideas and evaluate their work (Balci et al., 2005; Bybee, 2002; Eisenkraft, 2003; Liu et al., 2009; Llewellyn, 2005; Settlage, 1998; Wilson, Taylor, Kowalski & Carlson, 2010). The purposes of each phase, as well as specific activities that can be used to accomplish each goal in the 5E learning cycle are addressed in Table 1 below.
Table 1
5E Learning Cycle: Purpose and Activities (Adapted from Llewellyn, 2005)

<table>
<thead>
<tr>
<th>5E INSTRUCTIONAL MODEL PHASE</th>
<th>PURPOSE</th>
<th>ACTIVITIES</th>
</tr>
</thead>
</table>
| ENGAGE                       | • Introduce purpose of the lesson and create cognitive dissention | • Demonstrations  
   |                               | • Discrepent events  
   |                               | • Open-ended explorations  
   |                               | • Teacher directed activities  
   |                               | • Brainstorming  
   |                               | • Raise student questions  
   |                               | • Similarities and differences  
   |                               | • Setting objectives |
| EXPLORE                      | • Students build on common experiences | • Inquiry-based labs  
   |                               | • Cooperative groups  
   |                               | • Probing questions |
| EXPLAIN                      | • Concepts are explained and new terminology is introduced | • Discussions requiring student explanations and justification  
   |                               | • Student to student discourse  
   |                               | • Lecturing  
   |                               | • Audio/Visual  
   |                               | • Internet activities  
   |                               | • Simulations  
   |                               | • Summarizing/Note taking  
   |                               | • Homework |
| ELABORATE                    | • Reinforce concepts with activities that extend and apply the new information | • Use of new vocabulary  
   |                               | • Alternative explanations  
   |                               | • Applications to real-world situations/problems  
   |                               | • Role-play activities  
   |                               | • Labs that extend learned knowledge |
| EVALUATE                     | • Bring closure to the lesson and determine the student’s level of understanding | • Summarizing  
   |                               | • Class discussions  
   |                               | • Authentic assessments  
   |                               | • Concept maps  
   |                               | • Student reflection  
   |                               | • Representation that is not linguistic  
   |                               | • Interviews |

The effectiveness of the 5E learning cycle has been demonstrated in several different studies spanning a wide variety of subjects and grade levels (Liu et al., 2009; Musheno & Lawson, 1999; Tural, Akdeniz & Alev, 2010; Wilder & Shuttleworth, 2005).
It is important to note that these lessons encourage communication of ideas through writing, reading and communication with peers. The learning environment is mutually created through language and science skills. Using the 5E learning cycle to help students to develop these skills simultaneously will enrich their experiences and understandings in the science classroom (Bybee, 2002; Tobin, 1993).

METHODOLOGY

Pre-Study Interviews

To fully understand the impact this teaching method would have on my students, it was essential to first discover the variety of techniques to which they had been exposed in their educational careers. I also needed to understand student perception concerning the usefulness of those methods in achieving overall comprehension of the subject matter being introduced. Another area of consideration was to discover specific methods students prefer when learning new information, as well as the reasoning behind their choices. My final concern was to discover how confident my students felt in applying science and how they viewed writing in the science classroom.

Prior to the study, I chose to conduct a semi-structured interview with a focus group of 14 students, 57% male and 43% female. The range of grade levels represented was 36% seniors, 50% juniors, and 14% sophomores. These students also spanned a wide range of academic achievement, with 36% being high achievers (grade of A), 43% in the middle range (grades of B and C) and 21% showing low academic achievement (grades of D and below). This focus group participated in the Student Perception of Teaching Methods Survey that began individually with the administration of nine
interview questions (Appendix A). After responding to the initial questions, the students came together as one large group to discuss their answers.

The responses made during this interview provided insight into the thoughts of my students regarding their learning, as well as their overall unenthusiastic attitude toward the writing process in science. The reasoning behind their answers helped me to understand how important it is for the students to be actively engaged in their education. They all expressed a desire for teachers to make their learning relevant to experiences that will be encountered outside of their academic career. In addition, student participants articulated the need for opportunities to practice the new information in order to become more proficient in understanding and using the content.

Implementation of 5E Learning Cycle

In order to investigate the effects of the 5E learning cycle on student comprehension, application and development of scientific literacy, I taught three comprehensive biology units using the 5E learning cycle as my primary method of instruction. The units included cellular structure, genetics, and evolution and were taught in four biology classes composed of 42 students in grades 10-12. The project spanned a period of eight months, beginning in August 2011 and culminating at the end of March 2012. During this time, the students were engaged in activities that followed the steps outlined in the 5E learning cycle (Table 1) and emulated the criteria important to the constructivist way of thinking. The research methodology for this project received an exemption by Montana State University’s Institutional Review Board and compliance for working with human subjects was maintained. In addition to this, because the teaching
methods fell within the normal realm of classroom practices, my administrator chose to grant me administrative exemption in lieu of distributing informed consent forms to the parents of my students (Appendix B).

Assessment Techniques

Before beginning the research, it was essential to discover the scope of previous experiences my students have had in science classes. It was also imperative to find out what types of hands-on experiences they have participated in previous to this study. To accomplish this, students were given the Previous Science Experiences Survey (Appendix C), and the Student “Hands-On” Science Experiences Survey (Appendix D), both adapted from Yager (2009). Student responses were tallied and averaged to determine the frequency of participation indicated in each category.

Students were evaluated throughout the research process using a variety of assessment techniques. The methods assessed student comprehension of scientific content and processes, the development of scientific literacy skills and student perceptions throughout the entire project.

The assignments in which students participated required individual and group participation, as well as analysis and evaluation, through the application of content in the design and completion of inquiry activities. As students worked, they were assessed using the Scoring Rubric for Engagement in Essential Features of Inquiry (Appendix E), adapted from Yager (2009). This was accomplished through use of oral questioning as well as field notes that were recorded during observations of student interactions and assigned tasks. At the end of the project, student scores on these assignments were
compared using the mode for each section. Data was analyzed to determine longitudinal changes in scores as students progressed through the project; responses were analyzed to discover common themes throughout the study.

Following each inquiry, students performed an analysis of their data and procedures using the Scoring Guide for Laboratory Report (Appendix F). They were also asked to complete the Assessment of Team’s Performance (Appendix G), adapted from Yager (2009). These assessments required the students to articulate their ideas through writing, which served the dual purpose of allowing me to evaluate student comprehension of the content of an inquiry activity and evaluating the effect of the learning model on development of student scientific literacy skills. Scores on the data analyses and procedure sections of laboratory reports were assigned according to criteria outlined in the rubric on the Scoring Guide for Laboratory Report. Scores were tallied and averaged to determine growth of the students’ scientific literacy throughout the project. Student responses on the Assessment of Team’s Performance were also compared longitudinally during the project to determine whether any changes occurred in the ability of students to overcome challenges when working together in groups. Additionally, these responses were analyzed to ascertain any variations that occurred in the students’ understanding of proper scientific procedure, as well as their reasoning for procedural outcomes.

Furthermore, student comprehension of scientific content and processes was assessed at the culmination of each unit through a variety of authentic assessments including inquiry laboratories, research projects and case studies. Student scores were recorded and compared at the conclusion of the research project. This allowed me to determine the effects of implementing the 5E learning cycle on student achievement.
Specifically, students’ writing skills were assessed through Laboratory Assessments (Appendix F), Team Performance Assessments (Appendix G) and Journal Entries (Appendix H). Samples of student responses were collected throughout the study and analyzed for depth and conceptual understanding. These were compared at the culmination of the project to evaluate student growth in scientific literacy.

The students were also required to write a scientific paper twice during this study: at the beginning of the inquiry and at the conclusion of the project. Writing assignments required students to analyze, evaluate and explain the results and procedures of their individual science projects; they were assessed using the Scoring Rubric for Engagement in Essential Features of Inquiry (Appendix E). Again, student scores were collected and analyzed using the mode for each section of the rubric in order to determine growth in understanding and application of scientific literacy. Development of student’s oral communication skills, using scientific terminology and reasoning, was also assessed throughout this study by the use of interviews as well as observations of student interactions during inquiry activities.

Student perceptions regarding their comprehension of scientific content and literacy skills as a result of the use of the 5E learning was the final aspect addressed by this investigation. To evaluate this particular feature, I utilized journal prompts (Appendix H), as a tool, to assist students in their personal reflections. Responses were analyzed in order to determine common themes and outliers in the data.

It was also imperative to understand the students’ perceptions of their own academic gains as a result of the use of this learning model. To determine this, the
students were given the Student Perceptions of Mental Activities Survey (Appendix I), as well as the Student Perceptions of Activities Contributions to Their Growth Survey (Appendix J), both of which were adapted from Yager (2009). Students were further questioned using the Post-Activity Interview Questions, in which a small focus group of students participated in a semi-structured interview (Appendix K). This assessment allowed me to prompt the students with formal interview questions, while providing the opportunity to further probe their ideas via follow-up questions. Again, student responses were analyzed to determine common trends as well as irregularities in the data.

In order to ensure that the study questions were answered, it was essential to continuously monitor student comprehension through the use of the assessments previously described. The following matrix summarizes the data collection methods and timeline that were used to answer each of my research questions (Table 2).

Table 2
*Data Collection Methods*

<table>
<thead>
<tr>
<th>Data Collection</th>
<th>Timeline Months 1-6</th>
<th>Research Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(B) beginning (M) middle (E) end (T) throughout</td>
<td>Student Comprehension</td>
</tr>
<tr>
<td>Surveys</td>
<td>B, E</td>
<td>X</td>
</tr>
<tr>
<td>Interviews</td>
<td>B, E</td>
<td>X</td>
</tr>
<tr>
<td>Inquiry Process Analysis</td>
<td>T</td>
<td>X</td>
</tr>
<tr>
<td>Lab Assessments</td>
<td>M</td>
<td>X</td>
</tr>
<tr>
<td>Team Performance Assessments</td>
<td>M</td>
<td>X</td>
</tr>
<tr>
<td>Journals</td>
<td>T</td>
<td>X</td>
</tr>
<tr>
<td>Scientific Papers</td>
<td>B, E</td>
<td>X</td>
</tr>
</tbody>
</table>
DATA AND ANALYSIS

Previous Experiences of Students

Comparison of results obtained from the Previous Science Experience Survey (Appendix C) revealed that teacher centered instruction dominated the experiences of those surveyed ($N=43$). Listening to teacher lectures or instruction was reported by 74% of the students as having occurred often or very often. In addition, 49% of students reported viewing teacher demonstrations during nearly every class session. However, 100% of the students reported having had the opportunity, at least sometimes, for conducting hands-on activities and laboratories.

The Previous Science Experience Survey also showed that the majority of students had experience with all of the activities in question. Even so, there were still a small number of students who had not participated in some areas. The survey showed that the highest percentage of non-experience occurred in the area of student participation in science discussions, in which 14% reported never having had the opportunity to participate.

Responses gathered from the Student “Hands-On” Science Activities Survey (Appendix D) concurred with the hands-on experiences data above, showing that the majority of students participated in hands-on activities that required them to follow a given protocol (Figure 1). Nearly half, 49% of the students surveyed, indicated that hands-on activities were required nearly every time, while another 33% indicated participating in that activity at least every other time. In contrast, the survey revealed predominantly negative comments in response to questions regarding student control of
experimental procedures (Figure 2). Nearly half (47%) of the students claimed never to have had the opportunity to choose or design an experiment they were to perform, or to proceed even further and design an experiment of their choosing. Another 35% indicated that they only had control over experimental design about 20% of the time.

Figure 1. Student Responses Regarding Time Spent Following a Given Protocol, (N=43).

Figure 2. Student Control Over Experimental Design, (N=43).
Results of the “Hands-on” Activities Survey also showed that most student participants had experience with scientific literacy in the form of discussions, written lab reports, and the analysis and evaluation of scientific methods. Nearly three fourths (71%) indicated that they were required to analyze their results and evaluate their methods, as well as write a lab report often or very often when performing a hands-on activity. An additional 22% had been required to complete these particular activities some of the time. Furthermore, 79% of those surveyed reported that they engaged in peer discussion of their findings, at least some of the time, when engaged in hands-on learning.

**Content Comprehension**

Student comprehension of content was primarily analyzed using data obtained from eight chapter assessments, the type of which varied throughout the research timeframe. Data showed that student (n=37) understanding of content material depended on the given form of the evaluation. Students scored highest on the laboratory assessments in which they were required to explain content through hands-on activities and were allowed to discuss procedures and data with their lab partners. According to the data, 75% of students obtained a grade of C or better on the first laboratory assessment, 55% on the second, and 94% on the third. Results (Figure 3) also demonstrated that girls and boys scored equally well in hands-on activities with a lab partner. Passing scores with grade of C or above, for both genders, varied by only one percent on all three of these assessments.

The second type of student comprehension assessment was written and required students to apply the concepts they had learned through practical applications using case
studies and real world situations. Students again scored very well on practical application evaluations; 74% passing on the first, 48% on the second, and 81% on the third. Analysis of the scores using gender as a variable showed a small variation between girls and boys, with girls averaging slightly better scores over all (Figure 4). Results showed that 82% of girls passed the first assessment with a grade of C or above, as compared to 59% of the boys. The second evaluation showed boys faring slightly better than the girls, 47% with passing scores as compared to 39% of the females. The third evaluation showed girls scoring only one percent higher (87%) than the boys.

The above results from student comprehension assessments closely correlates with data gathered in the Student Perceptions of Mental Activities survey (Appendix I) (n=30). When asked how much the 5E learning cycle activities had emphasized certain mental activities, students largely responded that the 5E learning cycle had greatly emphasized the understanding of information and its meaning as well as explaining ideas

![Figure 3. Comparison of Passing Grades Between Boys and Girls for Lab Assessments, (n=37).](image1)

![Figure 4. Comparison of Passing Grades Between Boys and Girls for Practical Application Assessments, (n=37).](image2)
in their own words (Figure 5). According to the survey results, only three percent of students felt that these mental activities were used very little. In addition, the majority of students (70%) also indicated that the 5E learning cycle required them to make judgments about the value of information and then evaluate whether the conclusions were sound. Of those surveyed, 13% indicated that they participated in this activity very much and an additional 57% specified that they engaged in this activity quite a bit.

Figure 5. Student Perception of Mental Activities Emphasized by the 5E Learning Cycle, \(n=30\).

The final type of evaluation given was a written assessment requiring students to explain their knowledge of the concepts through multiple choice and essay questions. Analysis of these scores showed very few of the students were successful with this type
of assessment. On the first assessment, only two students received a grade of D, while all other students failed. The second multiple-choice evaluation demonstrated slightly better results with 24% of the students passing with a grade C or above, yet still lower performance compared to the previously discussed forms of assessments. Results indicated that boys were slightly more successful on this form of evaluation, 15% receiving a passing score as compared to 6% of girls.

Results in multiple choice-essay written assessments contradict the data gathered from the Student Perceptions of Mental Activities survey (Appendix I). Survey responses indicated that students believed that the 5E learning cycle activities emphasized memorizing facts and ideas so that they could repeat them in similar form. To further investigate the contradiction, I followed the survey with a journal entry prompt asking why students fared poorly on the written assessment, when they felt they had spent time memorizing facts and information. The majority of responses indicated that the wording on the tests was too difficult, and they did not understand what the questions were asking. One student in particular stated “I didn’t know half the words in the question so I just guessed an answer. If you could have just asked us in simple English I would have got it.”

Changes in student comprehension of content was evaluated using a pre and post-test \( (n=30) \). Results indicate that student comprehension of content increased an average of 52.5%. The pre-test data showed all students failing with an average score of 14.5%, and by the time of the post-test student scores increased an average of 48.9 points resulting in 50% of the students obtaining a grade of C or above.
Development of Scientific Literacy

Analysis of seven student laboratory write-ups with the Scoring Guide for Laboratory Reports (Appendix F) gave insight into the development of students’ (n=29) scientific literacy. Data demonstrated that students were most competent in writing a hypothesis for the intended investigations. In the first laboratory, 52% of students received a score of 2 out of a possible 4, indicating that the hypothesis was somewhat confusing or awkward and was missing some of the specified criteria. However, 34% were able to write a satisfactory hypothesis and received a score of 3. Their most common mistake was failing to link the effect to the variable. In subsequent laboratory write-ups, the number of students scoring a 3 on the hypotheses steadily increased: 66% on the second lab, 83% on the third, and 76% on the fourth. By the fourth lab, 24% of students attained a score of 4, indicating that they had met all of the specified criteria. The student’s ability to write a comprehensive hypothesis continued to improve over the next 3 laboratory write-ups, resulting in 93% of participants meeting all the specified criteria by the final lab assessment.

Analysis of the laboratory write-ups revealed that writing a comprehensive, understandable procedure posed a problem for students at the beginning of the semester. Participants were divided almost in half, 48% received 2 points and the other 52% obtained a score of 1. The laboratory procedures in the beginning did not effectively address the collection of sufficient, relevant data and made no indication as to how students could control the variables to reduce procedural error. In a follow-up interview students were asked what they felt was the most difficult part of the lab for them to accomplish. One of the most frequent responses was that students liked having the
procedures already written for them. One student, in particular, made the comment that they “did not like having to think about every single step and write it down so that someone else could repeat the experiment.”

Such procedural mistakes were steadily corrected by an increasing number of students as time progressed (Figure 6). Results showed that 76% of students obtained a score of 3 by the second laboratory assessment. At the 3rd and 4th laboratory assessments the percentage of students writing a procedure worthy of a perfect score of 4 was 41% and 62% respectively. By the 7th laboratory assessment, 76% of the students were able to successfully write a procedure that could easily be performed by somebody else. The seven remaining students who missed a perfect score struggled with clear descriptions of some procedures, resulting in confusion and the possibility of error when attempted by someone outside of our class. Students demonstrated their increased understanding of how to carry out a valid experiment through their responses on the Assessment on Team’s Performance Questionnaire (Appendix G), which was given after the third laboratory assessment. Results of this assessment (n=25) showed 100% of the students answering the questions correctly.
The most dramatic longitudinal change observed in the laboratory assessments over the study was in the area of observations and data (Figure 7). This section scored the lowest in the beginning with 55% of the students receiving a score of 0 out of a possible 4. This was a direct result of students failing to record any data over the course of the laboratory investigation.
The frustration over this part of the laboratory write-up became apparent in the follow up interview regarding the question of what was most difficult for the students to accomplish. Similar to responses on the difficulty of writing the procedure, students made comments that gathering and recording data was the most challenging. One student explained “I was having so much fun trying to figure out the problem that I forgot to take the time to record my measurements.” Another student became upset when the groups were required to compare results and graph the data. “I just forgot to do it. It is not fair that my plane isn’t counted even though it went the furthest.”

Despite the low scores for this section on the 1st laboratory write-up, by the 2nd laboratory assessment 55% of students achieved a score rating of 3. This indicated that students presented data that was clearly and logically organized, and they were missing less than three of the specified criteria. The missing items were incomplete data entries and either unlabeled or mislabeled columns and axis. Improvement continued by the 3rd laboratory assessment when nearly 83% of the students obtained a score of 3. Analysis of the data showed student scores increased again rather dramatically at the 4th lab assessment, as 76% of students obtained a perfect score of 4 for the observation and data section of their lab report.

As the fifth through seventh laboratories became more difficult and took longer periods of time to complete, student scores on data and observations actually changed direction, showing a steady decrease in points earned. Seven percent of the students dropped from a score of 4 to a score of 3 on the 5th lab, and an additional 10% dropped down to a score of 3 on the 6th lab. By the 7th lab only 48% of the students obtained a score of 4, 38% a 3 and 14% dropped to a score of 2. The drop in scores was a result of
students failing to record and graph all of the data throughout the inquiry. When asked about the sudden change in their ability to properly record and graph the data, several students commented on the amount of data being overwhelming because the lab inquiry lasted several days rather than being completed in one class period. One of them made the remark “I didn’t know we had to write something down every day. I thought we could just put it all together in the end.” Two other students replied that they had missed a class period due to extracurricular activities and failed to get the data from their lab partner. An additional three students stated that they were “lazy” and just “didn’t want to do it” after which they laughed and shrugged their shoulders.

Results summarized in Table 3 are for the final assessment of lab report sections, specifically the results and conclusions obtained from the experimental procedures. Scores for the first lab write-up averaged 7.5 points out of a possible 15. Most points were deducted for students failing to record details about what happened and why, as they made no attempt to relate their results to what they had learned about the concept. Students also omitted final analysis of the relationships and patterns found in the data, as well as the identification of possible errors and recommendations for additional experiments to further clarify their results.

Table 3
Summary of Student Scores on Lab Report (n=29), scores out of 15 possible points

<table>
<thead>
<tr>
<th>Lab #</th>
<th>Avg. Score</th>
<th>% Increase</th>
<th>% Decrease</th>
<th>% No change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>10.9</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>7.1</td>
<td>16%</td>
<td>63%</td>
<td>21%</td>
</tr>
<tr>
<td>4</td>
<td>11.8</td>
<td>55%</td>
<td>10%</td>
<td>35%</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>37%</td>
<td>53%</td>
<td>10%</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>71%</td>
<td>18%</td>
<td>11%</td>
</tr>
<tr>
<td>7</td>
<td>13.6</td>
<td>43%</td>
<td>19%</td>
<td>38%</td>
</tr>
</tbody>
</table>
Assessment of the second lab report indicated that all students showed increased understanding of the relationships in observations, as well as how to find the patterns and relate it to the concepts being learned in class. The students also improved in the areas of identifying possible sources of error and suggesting solutions to make the results more accurate.

Assessment of the third lab showed a substantial decrease in the average score obtained by the students. Because 34% of students failed to write anything in this section of the report, the average score for this assignment dropped to 7.1. Among scores for the 19 students who did write a conclusion, 63% decreased by 1 or 2 points because they did not relate what was discovered in their procedures to the concepts learned in class.

Data from the final 4 laboratory assessments showed small fluctuations in the student’s scores culminating in an average score of 13.6. The majority of chronic errors committed by these students were an inability to relate their experimental results to the concept being studied in class, as well as difficulty in identifying real-world application without supplementary help from me.

The data also showed that the number of students obtaining a perfect score on the conclusion portion of their laboratory write-ups steadily increased from 7% on the 4th laboratory assessment, to 29% on the 6th, and to 38% on the final laboratory 7 write-up. Despite these increases, there were still 62% of the students receiving point deductions for failing to relate the data obtained to the concepts being learned, as well as how it could be applied to real-world situations. When talking with several of the students in this category individually, I found that with a few prompts they were able to more easily
relate their laboratory data to the broader concepts being discussed. One student summed up the other’s responses by stating “I don’t get it until I talk to you, then it makes sense and I feel stupid for not doing it myself.”

The development of scientific literacy within my students was confirmed by the data gathered from the Scoring Rubric for Engagement in Essential Features of Inquiry (Appendix E), which was used to assess the students’ two science projects (Figure 8).

Engagement results in the first science project, completed at the beginning of this study, showed students having difficulty engaging in scientifically-oriented questions and not being able to communicate and justify their explanations after gathering the data. A majority (79%) of students \(n=28\) had to have their scientific questions posed by me and therefore only received a score of 1 out of a possible 4. The remaining 21% received a score of 2 because they were able to clarify questions that I provided. In contrast, by the second project completed at the end of the study, all students showed improvement in their ability to engage in scientifically-oriented questions: 43% obtained a score of 2 and 57% scored a 3 because they were able to select among questions and then pose their own.
Student Scores for Essential Features of Inquiry, \((n=28)\).

Initial low scores were also observed for the second section of the assessment on the ability of the students to communicate and justify their explanations at the culmination of their projects. The majority of the students, 79\%, had to be given the specific steps and procedures for communication, resulting in a score of 1 out of a possible 4 points. The remaining six students received a score of two as a result of being able to communicate their results with the help of more general guidelines. Similar to improvements noted above, this section showed a dramatic increase by the second project in that 43\% of students scored a 3, and an additional 18\% of the students achieved a perfect score for their ability to form reasonable and logical arguments to communicate their explanations.

Students showed the highest competency in giving priority to evidence in responding to questions posed in their investigations. Only 14\% of the students had to be
instructed on how to gather appropriate data for analysis. These students received a score of two out of a possible four. The remaining 86% received a score of 3, as they were able to collect and analyze their own data with minimal direction. Even from the relatively higher scores in the beginning, students still showed improvement by the time of their 2\textsuperscript{nd} assessment: student scores increased to 43% at a score of 3, while 54% scored a perfect 4. This demonstrated their capacity for growth in their ability to determine what constituted evidence, collect it and then analyze it.

The remaining two sections of the Engagement in Inquiry assessment also showed an increase in student understanding. In the beginning, 75% of the students had to be given possible ways to use the evidence and formulate explanations. This changed to 46% of the students requiring minimal direction in collecting and analyzing data on their own, with an additional 43% being able to determine what constituted evidence and then collect and analyze it on their own.

In regards to the ability to connect explanations to the scientific knowledge gained through research, 50% of students had to be provided with the connections at the time of the first assessment, while the other 50% had to be given possibilities and then were able to come up with their own associations. The 2\textsuperscript{nd} project data showed that, although 54% of students were able to find scientific knowledge on their own after a small amount of direction toward possible sources, another 36% were able to independently examine other resources and form links to their explanations.
Student Perceptions of 5E Learning Cycle as Primary Method of Instruction

Overall, the increase in scientific literacy skills correlated with the students’ perception of how the 5E learning cycle contributed to their growth (Figure 9). The majority of students, 89%, indicated that this teaching method had helped them very much or quite a bit in making observations, developing questions and thinking deeply and critically (n=27). The area showing the largest variation in responses was that of writing effectively. The students were distributed almost equally, 30% indicating that the 5E learning cycle helped them very much, 37% quite a bit, and 30% signifying that it had only helped them some. All students expressed that the 5 E learning cycle had contributed to their growth in collaborating with their peers.

Figure 9. Student’s Perceptions of the 5E Learning Cycle Contributions to Growth, (n=27).
Analysis of the Post-Activity Interview (Appendix K) responses gave additional insight into the student’s perceptions of using the 5E learning cycle as a primary form of instruction. Only 13% of students interviewed ($n=30$) made negative comments about the use of the learning method when they were being introduced to new science concepts. Their main criticism was they preferred knowing what they were going to learn before beginning hands-on, investigative activities. One student made the comment “It is hard for me to follow I don’t like to wait to find out what I am learning about.”

In contrast, those who preferred the method over traditional teaching strategies found the 5E learning cycle gained their interest more effectively and keep them engaged in the content being studied. Comments such as “I like it, it helped me be aware of the concept,” “it teaches more detail,” and “it’s easier, more hands-on and makes you think more,” indicated specific reasons why the majority of the students favored this teaching method.

The next section of the interview asked students about their observations on the strengths and weakness of the 5E learning cycle. Responses regarding the strengths showed that students felt this teaching method encouraged them to explore concepts in more depth and caused them to devise questions on their own. Many students also mentioned that they felt more ownership over their learning; they believed that this instructional strategy invited them to be more active, to create their own ideas, and to utilize the material and concepts in ways that made sense and created an understanding of the relevance of science to real-world situations.
In contrast to the strengths noted above, some of the students believed this teaching method was too difficult because there were too many activities. One student in particular stated, “This method has so many projects and you do so much that it is hard to make it all up if you miss a day of class.” This section of the interview also revealed a discrepancy in student perception that correlated with their preferred style of learning: one student said that lectures needed to be more expansive, three others stated that they hated the lecture associated with the explain section of the 5E learning cycle.

The final section of the interview asked students to explain how the use of the 5E learning cycle affected their understanding of science concepts and process as well as their ability to communicate through writing. Positive influences were referenced by 97% of the students in relation to comprehension of concepts and processes. Specific annotations were “know more detail,” “have a better overview,” “actually remembered things I learned,” and “better – not only do we talk about it we also do it.” Only one student said that it made it affected her negatively because she “didn’t understand as much.”

In response to how the 5E learning cycle affected communication through writing, positive feedback dropped slightly to 90% of students responding that they were influenced in a helpful manner. One student’s response represented all the rest, “It has given me a new perspective on writing. I can write more because I now know what I am talking about!” Those students who believed their writing was negatively impacted by the use of the 5E learning cycle stated that it did not help because they “don’t like to write,” and “would rather explain verbally.”
INTERPRETATION AND CONCLUSION

This study provides evidence that the 5E learning cycle is an effective method for developing scientific literacy in students. Responses on the laboratory write-ups and practical application assessments coupled with the positive comments made on the Post-Activity Interview Questions (Appendix K) support the premise that the most effective methods of teaching are inquiry based (Krajcik & Sutherland, 2010). The continued development throughout the study of student’s ability to read, write and communicate about science represents gains in scientific literacy as an outcome of the 5E learning cycle. The change in the students’ written and verbal communication, along with their increased ability to apply scientific content to real-world situations has convinced me to make this a primary method of instruction in my classes.

An important contrasting outcome, however, was the observation that development of student comprehension of content seemed to be less developed as a result of using this method of instruction, as compared to traditional teaching methods of lecture followed by hands-on laboratory activities. This effect on comprehension of content could be the result of several factors, the first being attributed to my inexperience at delivering the 5E learning cycle instruction. Further development of the explanation portion of this teaching method could be implemented as a way to address the development of content knowledge in my students.

Another important factor in the observed delay of content comprehension was a direct result of the limited vocabulary in my students, not only of science content but also general terminology. Evidence from this study showed students could easily answer
assessments when they were questioned orally and the unfamiliar terminology was explained. On the other hand, students floundered when they were required to read the questions without an oral explanation. This leads me to believe that incorporating additional instructional techniques focusing on scientific vocabulary could prove to aid in the content comprehension of my students.

VALUE

Developing and implementing this study has proved to be a great learning experience for me, as it has positively influenced my methods of teaching. During my courses in the MSSE program, I have learned more effective methods for instructing my students. These methods have directed me away from the traditional way of teaching, utilizing lecture with follow-up laboratory activities, to a teaching style that is rich with inquiry and practical application investigations focused on developing the critical thinking skills of my students.

As a result of this increase in inquiry, the majority of my students have become proficient in the area of scientific literacy. They have grown in their ability to do science, to ask questions, devise procedures for finding answers to their problems, and finally to analyze the data they have collected and apply it in a reasonable fashion. I am now able to give them a variety of real world situations which require application of the content they have learned to find plausible solutions. They have also become very successful in talking about science, explaining ideas to others, and communicating the results of their investigations. In my previous years of teaching, I have not seen student growth in these areas to the degree that I have experienced this year.
This study has also revealed to me that my students struggle in development of content comprehension due to their limited vocabulary. Much of this can be attributed to my focus on the inquiry part of the 5E learning cycle at the expense of a quality explanation and development of vocabulary that would aid my students in the comprehension of the content.

During the coming school year, my professional goals will center on further development of skills in using the 5E learning cycle. I have become skillful in my abilities to design and implement a curriculum that requires inquiry on the part of my students. With further development of differentiated teaching strategies, I believe my students will continue to develop their critical thinking skills and be able to continuously increase their scientific literacy. Furthermore, I will concentrate on creating vocabulary lessons to supplement the explanation portion of the 5E learning cycle. With an added focus on development of biology terms, I am confident my students will exhibit increases in comprehension of course content and improve their ability to do science successfully.

Furthermore I will continue to develop practical application activities that encourage students to apply what they have learned to real-world situations. The 5E learning cycle has contributed greatly to a feeling of success within my students, which is centered on their ability to carry out an effective scientific procedure. I want to use this newfound confidence to help the students overcome the status quo and engage in activities that will foster their understanding of science as important in their lives and will be useful in a variety of situations that they will inevitably encounter.
Continued implementation of the 5E learning cycle as my primary means of instruction will help my students envision success in the development of their science literacy and critical thinking skills. Performance of this study has helped me to realize how important it is to continuously monitor my students’ learning development and to use the results of my data to develop strategies that will continue to foster their understanding of content and processes. Classroom research will now be an integral and permanent part of my own professional development, because the possibilities for learning and self-improvement as a professional educator are endless.
REFERENCES CITED


APPENDIX A

STUDENT PERCEPTION OF TEACHING METHODS SURVEY
Student Perception of Teaching Methods Survey

1. How do you prefer to learn while in class (on your own, lectures, group activities, etc.)? Explain.

2. What are your feelings about interactive learning (active participation in lecture, group work, and hands-on activities)?

3. How do you think your learning within the classroom can be made more relevant to your own life outside of school?

4. Think of a particular class in which you feel that you learned the most (you can still remember the content that was taught). Why do you think you remember so much from that class? What made the material stick with you?

5. Think of a particular class in which you feel you did not learn as much as you would have liked (you cannot remember the content that was taught). Why do you think it was more difficult to retain any content learned in this class?

6. Are there any particular teaching methods (techniques) that you can think of that help you to learn the required content more effectively?


8. If you were asked to explain a scientific process, or idea, how well do you think you could articulate your thoughts? Why?

9. List some things that I might do to help you improve your science literacy skills.
APPENDIX B

ADMINISTRATOR EXEMPTION REGARDING INFORMED CONSENT
Administrator Exemption Regarding Informed Consent

I, John Allen, Principal of Round Valley High School, verify that the classroom research conducted by Charlotte Hagerman is in accordance with established or commonly accepted educational settings involving normal educational practices and that I approve the project. To maintain the established culture of our school and not cause disruption to our school climate, I have granted an exemption to

Charlotte Hagerman regarding informed consent.

(Signed Name, Title of Position)

John Allen
(Printed Name)

4/27/11
(Date)
APPENDIX C

PREVIOUS SCIENCE EXPERIENCES SURVEY
## Previous Science Experiences Survey

<table>
<thead>
<tr>
<th>How much time in your previous science classes did you spend…</th>
<th>Very often (multiple times/class)</th>
<th>Often (nearly every class)</th>
<th>Sometimes (several times/week)</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>…listening to a teacher lecturing/talking?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…completing worksheets concerning science?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…watching a teacher demonstration?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…presenting/reporting on science?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…conducting hands-on activities/labs?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…engaged in student discussion of science?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D

STUDENT “HANDS-ON” SCIENCE ACTIVITIES SURVEY
# Student “Hands-On” Science Activities Survey

<table>
<thead>
<tr>
<th>If you engaged in hands-on activities how much time did you...</th>
<th>Very Often (nearly every time)</th>
<th>Often (every other time)</th>
<th>Sometimes (~ 1/5 of the time)</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>…spend observing and questioning a problem?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…follow a given protocol (set of instructions)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…determine experimental controls?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…choose the experiment?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…design the experiment?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…design an experiment you wanted to perform?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…make graphs, tables, charts?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…discuss your findings with your peers?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…analyze your results and evaluate your methods?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…write a lab report?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>…write in the form of a scientific paper?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX E

SCORING RUBRIC FOR ENGAGEMENT IN ESSENTIAL FEATURES OF INQUIRY
### Scoring Rubric for Engagement in Essential Features of Inquiry

<table>
<thead>
<tr>
<th>Score</th>
<th>Essential Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner engages in scientifically oriented questions</td>
<td>Learner needs to have questions posed by teacher</td>
<td>Learner can clarify questions provided by teacher</td>
<td>Learner selects among questions and then poses new questions</td>
<td>Learner poses own questions</td>
<td></td>
</tr>
<tr>
<td>Learner gives priority to evidence in responding to questions.</td>
<td>Learner needs to be given data and told how to analyze it</td>
<td>Learner needs to be provided with data and then is able to analyzes it on their own</td>
<td>Learner needs direction in order to collect and analyze certain data on their own</td>
<td>Learner determines what constitutes evidence, collects it and then analyzes it</td>
<td></td>
</tr>
<tr>
<td>Learner formulates explanations from evidence.</td>
<td>Learner needs to be provided with the evidence</td>
<td>Learner is given possible ways to use evidence and formulate explanations</td>
<td>Learner is guided in the process of formulating explanations from evidence</td>
<td>Learner formulates own explanation after summarizing data</td>
<td></td>
</tr>
<tr>
<td>Learner connects explanations to scientific knowledge.</td>
<td>Learner is provided with the connections</td>
<td>Learner is given possible connections</td>
<td>Learner is directed toward areas and sources of scientific knowledge</td>
<td>Learner independently examines other resources and forms the links to explanations</td>
<td></td>
</tr>
<tr>
<td>Learner communicates and justifies explanations.</td>
<td>Learner is given steps and procedures for communication</td>
<td>Learner is provided broad guidelines to sharpen communication</td>
<td>Learner is coached in the development of communication</td>
<td>Learner forms reasonable and logical argument to communicate explanations</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F

SCORING GUIDE FOR LABORATORY REPORT
<table>
<thead>
<tr>
<th>Section of Report</th>
<th>Score</th>
<th>Comments</th>
</tr>
</thead>
</table>
| **Initial Question**           | 3 2 1 0 | 3 – Question is clearly stated and relates directly to the experimental procedure  
|                                |       | 2 – Question is slightly abstract or unclear and not directly related to the experiment  
|                                |       | 1 – Question is not relevant to experiment  
|                                |       | 0 – Question is missing                                                   |
| **Hypothesis**                 | 4 3 2 1 0 | 4 – All criteria are addressed. The hypothesis is stated in a clear, concise statement that fits well with the research question  
|                                |       | 3 – One of the specified criteria is missing. The hypothesis is satisfactory  
|                                |       | 2 – Two of the specified criteria are missing. The hypothesis is awkward, confusing or lengthy in nature  
|                                |       | 1 – Three of the specified criteria are missing. The hypothesis is not written clearly or its length is cumbersome  
|                                |       | 0 – Hypothesis is missing                                                |
| **Procedure for Investigation**| 4 3 2 1 0 | 4 – All criteria are addressed. The methods used to control internal validity and collect sufficient, relevant data are described clearly and accurately.  
|                                |       | 3 – One of the specified criteria is missing. The methods follow principles of proficient experimental design to collect sufficient, relevant data and limit  
|                                |       | 2 – Two of the specified criteria are missing. The methods are cumbersome  
|                                |       | 1 – Three of the specified criteria are missing. The methods are confusing or lengthy in nature  
|                                |       | 0 – Hypothesis is missing                                                |
procedural error.
2 – Two of the specified criteria are missing. The method shows problems in the collection of sufficient, relevant data and controlling variables to reduce procedural error.
1 – Most of the specified criteria are missing. The method does not address the issue of collecting sufficient, relevant data and does little to control variables and limit procedural error.
0 – Procedure is missing

Observations and Data Table Scoring Guide
• Title
• Column headings indicate what is being measured
• Column headings indicate units of measurement
• Independent variable in increasing order
• Data correctly and completely entered

4 3 2 1 0

Graph Scoring guide
• Title
• Independent variable is on the horizontal axis
• Horizontal axis is labeled
• Horizontal axis label includes units of measurement
• Appropriate scale on the horizontal axis (even intervals)
• Vertical axis labeled
• Vertical axis label includes units of measure
• Appropriate scale on the vertical axis (even intervals)
• Points plotted accurately
• Connects data points and

4 3 2 1 0

4 – All criteria are addressed. The strategies chosen for data manipulation and analysis show exceptional capability.
3 – Less than three of the specified criteria are missing. Data is clearly and logically organized using tables, charts and graphs where appropriate. Everything is correctly labeled.
2 – Several specified criteria are missing. Data has been presented but the chosen format is not the most appropriate for the job.
1 – More than half of the specified criteria are missing. Data is presented in an unorganized manner with frequent errors.
0 – The data is missing or there is no organization to the data.
Legend indicates which data is indicated by each line if there is more than one

<table>
<thead>
<tr>
<th>Results and Conclusion</th>
<th>REE</th>
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<td>0 – The discussion is</td>
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4 – All criteria are addressed. The discussion is well-thought-out and leads the reader through an excellent interpretation of the data.

3 – Less than three of the specified criteria are missing. The discussion arrives at a conclusion based on a valid interpretation of the collected data.

2 – Several of the specified criteria are missing. The discussion arrives at a conclusion. However the interpretation of the results is not based on the collected data.

1 – More than half of the specified criteria are missing. The discussion does not arrive at a suitable conclusion. The data collected is not used in the analysis.

0 – The discussion is missing or has no relevance to the procedure or data collected.
APPENDIX G

ASSESSMENT ON TEAM’S PERFORMANCE
Assessment on Team’s Performance

1. State the nature of the problem and the research question your team decided on. 
   What were some of the other questions debated…why settle on this one?

2. Describe some of the background research related to how…

3. What is an independent variable? What was the one used in this case? How did you go about changing it?

4. What is a dependent variable? What is your dependent variable in this case? How did you go about recording this? Were there other dependent variables considered?

5. What is a control set-up? What did your team use as a control in this situation? Why was this done?

6. What variables did the team decide were necessary to keep constant in order to maintain internal validity? Discuss how your method attempted to maintain these variables.

7. Discuss the results relative to your hypothesis…what did you find out? What conclusions can you make about the work (why do you think it happened the way it did?).

8. Comment on the experimental error (tightness) of the investigation. If internal validity was compromised… what were those errors or difficulties? How could you modify the work to improve validity if you could repeat your work?

9. **Group Answer**: What future questions might be studied as extensions to the investigation you have discussed today? Other comments?
APPENDIX H

JOURNAL ENTRY PROMPTS
Journal Entry Prompts

1. The most difficult part of designing today’s inquiry was…
2. In performing today’s inquiry I felt confident in my ability to…
3. Today’s inquiry showed that my skills are improving in…
4. I struggle with these things when I do inquiry…
5. Today’s inquiry activity made me feel…
6. Using the inquiry process has helped me…
APPENDIX I

STUDENT PERCEPTIONS OF MENTAL ACTIVITIES
Student Perceptions of Mental Activities

<table>
<thead>
<tr>
<th>How much has the 5E learning cycle activities emphasized the following mental activities:</th>
<th>Very Much (Almost all of the time)</th>
<th>Quite a bit (Nearly every time)</th>
<th>Some (About ½ of the time)</th>
<th>Very Little (Once in awhile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memorizing facts/ideas so that you can repeat them in similar form?</td>
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<tr>
<td>Understanding information and its meaning?</td>
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<tr>
<td>Being able to explain ideas in your own words?</td>
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<tr>
<td>Make judgments about the value of information/evaluate whether conclusions are sound?</td>
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</table>
APPENDIX J

STUDENT PERCEPTIONS OF ACTIVITIES CONTRIBUTIONS TO THEIR GROWTH
Student Perceptions of Activities Contributions to Their Growth

<table>
<thead>
<tr>
<th>How much has the 5E learning cycle activities contributed to your growth in the following areas:</th>
<th>Very much</th>
<th>Quite a bit</th>
<th>Some</th>
<th>Very little</th>
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<tr>
<td>Making observations?</td>
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<tr>
<td>Developing questions?</td>
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<tr>
<td>Thinking deeply and critically?</td>
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<td>Writing effectively?</td>
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<td>Collaborating with your peers?</td>
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APPENDIX K

POST-ACTIVITY INTERVIEW QUESTIONS
Post-activity Interview Questions

1. How do you feel about the use of the 5E learning cycle when being introduced to new science concepts? Explain.

2. In your opinion, what are the strengths of the 5E learning cycle?

3. In your opinion, what are the weaknesses of the 5E learning cycle?

4. How does the use of the 5E learning cycle compare with the more traditional teaching methods used in your previous classes?

5. How has the use of the 5E learning cycle affected your understanding of science processes and science concepts?

6. Has the use of the 5E learning cycle affected your ability to communicate your understanding through writing? Explain.

7. Is there anything else you would like me to know?