

---


Electronic Theses and Dissertations, 2004-2019

---

2009

## Can Guided Inquiry Based Labs Improve Performance In Data Analysis And Conclusion Synthesis In Sixth Grade Life Science?

Melonie Moore  
*University of Central Florida*

 Part of the [Science and Mathematics Education Commons](#)  
Find similar works at: <https://stars.library.ucf.edu/etd>  
University of Central Florida Libraries <http://library.ucf.edu>

This Masters Thesis (Open Access) is brought to you for free and open access by STARS. It has been accepted for inclusion in Electronic Theses and Dissertations, 2004-2019 by an authorized administrator of STARS. For more information, please contact [STARS@ucf.edu](mailto:STARS@ucf.edu).

---

### STARS Citation

Moore, Melonie, "Can Guided Inquiry Based Labs Improve Performance In Data Analysis And Conclusion Synthesis In Sixth Grade Life Science?" (2009). *Electronic Theses and Dissertations, 2004-2019*. 4144.  
<https://stars.library.ucf.edu/etd/4144>

**CAN GUIDED INQUIRY BASED LABS IMPROVE PERFORMANCE IN DATA  
ANALYSIS AND CONCLUSION SYNTHESIS IN SIXTH GRADE LIFE SCIENCE?**

by

MELONIE ANN MOORE  
B.A. University of Central Florida, 1992

A thesis submitted in partial fulfillment of the requirements  
for the degree of Master of Education  
in the Department of Teaching and Learning Principles  
in the College of Education  
at the University of Central Florida  
Orlando, Florida

Summer Term  
2009

©2009 Melonie Ann Moore

## **ABSTRACT**

Desiring to examine the performance of science process skills such as data analysis and conclusion synthesis in sixth grade Life Science students, I used an inquiry strategy called “guided inquiry” in a series of six laboratory assignments during the normal county-mandated order of instruction for Life Science. I based my analysis upon these laboratory exercises, a survey of student attitudes towards science done before the study began and after the study completed, an assessment of inquiry understanding done before and after the study was finished, routine material tests, and a science final class evaluation done after the study was finished. Emphasis was placed upon examining the content of the laboratory reports which required students to analyze their experiments and draw a conclusion based upon their findings. The study found that while most students did grasp the desired scientific principles the labs were designed to teach, they had difficulty in formulating a structured and detailed account of their experiences without guidance. The study helped to further understanding of student performance and learning in science process skills such as data analysis and conclusion synthesis.

## **ACKNOWLEDGMENTS**

I would gratefully like to acknowledge the support, encouragement and patience of the faculty and staff at the Lockheed Martin/UCF Academy in helping and occasionally pushing me to finish this Master's Degree. The wisdom, insight and experience of the Lockheed Martin/UCF Academy faculty has profoundly influenced me professionally. I particularly would like to thank my advisor Dr. Juli K. Dixon for her incredible devotion to the teaching profession and this university. I would like to thank Dr. Robert Everett for being my chair, and for his patience, advice, and help in seeing me through this all consuming endeavor. I would also like to thank Dr. David Boote and Dr. Lewis Blessing for being on my committee as well as their patience, encouragement and help in finishing this lengthy project.

## TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION.....	1
Rationale for Study .....	1
Purpose of the Study .....	3
Guiding Principles of the Study .....	4
Assumptions.....	5
Limitations .....	5
Delimitations.....	6
Definitions.....	6
Significance of Study.....	8
Summary.....	10
CHAPTER TWO: LITERATURE REVIEW .....	12
Introduction.....	12
A Framework for Scientific Inquiry .....	12
How Students Learn Science .....	16
Developing Scientific Reasoning in Children.....	19
How Students Reason from Data.....	21
Developing Science Process Skills in Students .....	26
Summary.....	31
CHAPTER 3: METHODOLOGY .....	35
Introduction.....	35
Design of the Study.....	36
Setting.....	38
Procedures.....	39
Methods of Data Collection.....	44
Methods of Data Analysis.....	46
CHAPTER 4: RESULTS.....	48
Introduction.....	48
Emerging Themes .....	48
Data and Analysis of Student Science Surveys .....	52
Data Analysis of the Final Class Evaluation.....	58
Data Analysis of the Inquiry Assessments.....	61

Analyzing the Laboratory Exercises .....	62
Data Analysis of the Chapter Test .....	64
Learning to Analyze Data .....	65
Learning to Synthesize Conclusions .....	66
Learning Content Material .....	67
CHAPTER 5: CONCLUSIONS .....	68
Introduction.....	68
Performance in Analyzing Data.....	70
Performance in Conclusion Synthesis .....	71
Discussion.....	73
Recommendations.....	74
APPENDIX A: IRB APPROVAL LETTER.....	75
APPENDIX B: SCIENCE SURRVEY APPROVAL.....	77
APPENDIX C: SCIENCE SURVEY .....	79
APPENDIX D: INQUIRY ASSESSMENT .....	82
APPENDIX E: CLASS EVALUATION.....	88
APPENDIX F: DIFFUSION LABORATORY EXERCISE .....	91
APPENDIX G: OSMOSIS LABORATORY EXERCISE .....	95
APPENDIX H: RESPIRATION LABORATORY EXERCISE .....	100
APPENDIX I: CELL MEMBRANE LABORATORY EXERCISE.....	106
APPENDIX J: CHAPTER TEST .....	111
LIST OF REFERENCES.....	114

## LIST OF TABLES

Table 1: Pre-Science Survey of Student Perceptions about Inquiry Learning.....	53
Table 2: Post-Science Survey of Student Perceptions about Inquiry Learning.....	54
Table 3: Pre-and Post-Science Surveys of Student Inquiry Learning.....	56
Table 4: Pre-Science Survey of Student Perceptions about Working with Others.....	57
Table 5: Post-Science Survey of Student Perceptions about Working with Others .....	57
Table 6: Pre-and Post-Science Surveys of Student Perceptions about Working with Others .....	58
Table 7: Class Evaluation of Student Perceptions about Help Received in Class Activities .....	59
Table 8: Class Evaluation of Student Perceptions about Help Received in Learning Skills.....	60
Table 9: Class Evaluation of Student Perceptions about Help Received in Improving Tasks ....	61
Table 10: Pre-and Post-Inquiry Assessments of Student Inquiry Learning in Problem Solving..	62
Table 11: Analysis of Inquiry Processes Required in Lab Exercises .....	64
Table 12: Analysis of Test Questions Relating to Science Concepts in Labs .....	65



## CHAPTER ONE: INTRODUCTION

### Rationale for Study

“A sound grounding in science strengthens many of the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning” (National Research Council, 1996, p. ix).

Inquiry based teaching in science is currently being adopted nationwide in many school districts as the best method to teach science at all levels. The local school district is no exception. A full inquiry based course has already been trialed and instituted in seventh-grade for Physical Science. A trial for an inquiry based course in Life Science for sixth-grade was begun in 2009 in several schools. If successful, this course will be instituted throughout the county for sixth-grade Life Science. The push away from traditional methods of teaching science to teaching science using inquiry based methods is sanctioned by the National Research Council as the way to improve national science literacy in the United States (National Research Council, 1996).

In 1996 the National Research Council authorized and funded a study called the *National Science Education Standards* through a branch committee known as the National Committee on Science Education Standards and Assessment. This report is referred to as the *Standards* in this study. The National Research Council describes the *Standards* as a blueprint for radical change in American schools. The *Standards* described a new way of teaching and learning science that is finally patterned after how science is actually done. Inquiry based teaching is promoted by the *Standards* as a way of gaining knowledge and understanding about the real world. The *Standards* also advocates dramatic changes in content material, assessment of student

performance, teacher education and continuing teacher education, and in the relationships between schools and the rest of the community, which includes the nation's scientists and engineers. The *Standards* champions making scientific knowledge, understanding and ability a primal part of the educational process because science has become a central part of our technology-driven society (National Research Council, 1996).

Inquiry as a method for teaching science figures prominently in the *Standards* as the premier method to improve science learning in the United States (National Research Council, 1996). Inquiry is defined in the *Standards* as going beyond the traditional method of teaching science, which emphasized the memorization of facts. The National Research Council (1996) stated that:

Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, construction and analyzing alternative explanations, and communicating scientific arguments. (p. 105)

My action research focused on the ability of sixth-grade science students to logically analyze data from their guided inquiry based laboratory experiments, ascertain any relationships between experimentally derived data, and synthesize a conclusion which explained how the data occurred. The ability to reason, which includes the ability to think critically and logically about the relationships between evidence or data and the explanation behind how this evidence came into being, is crucial to understanding not only science but life itself. People must have the ability to reason and understand the relationships between results and actions in order to make the best decisions possible for themselves and their loved ones. These skills are essential in science education and critical for everyday life (National Research Council, 1996). For example, if our

water supply is polluted by industrial toxins, we need to understand how the toxins got in the water supply before we will be able to stop the contamination.

### Purpose of the Study

Our world is becoming more complex technologically in every area from communication to health care to education to work to life itself. According to the National Research Council our technology-driven world is filled with the results of scientific inquiry processes and so scientific literacy has become a necessity. Therefore the National Research Council reasons that everyone needs to use scientifically-based information to make choices daily. Everyone needs to be able to reason and speak intelligently in public forums and debates about important issues that involve science and technology. All individuals should be able to share in the wonder that can come from understanding the natural world around them (National Research Council, 1996).

The National Research Council also observed that scientific literacy is becoming increasingly important in the workplace as more and more jobs demand advanced technological skills which require people to be able to learn, reason, think creatively, make decisions, and solve problems. Understanding both science and science processes contributes in an essential way to these skills. The National Research Council notes that many countries today are investing heavily to create scientifically and technically literate work forces. To keep pace in global markets, the United States needs to have an equally scientifically literate and technically literate workforce (National Research Council, 1996).

The question of whether or not inquiry can improve science thinking in the area of analyzing data and developing an explanation for that empirical data demands an answer. This vital question needs an answer because of the critical relationship between developing scientific

reasoning and the ability to see relationships between evidence and explanations, and the ability to reason and see relationships between occurrences and the problems of everyday life and the work place. Inquiry is being touted by the National Research Council as a way to develop these skills (National Research Council, 1996). Many school districts in the United States are now implementing inquiry based science education and abandoning traditional methods of teaching science. Can inquiry really help the United States achieve critical science literacy, and develop a scientifically and technically literate workforce necessary to compete in the global workplace? Specifically, can guided inquiry based labs improve the performance in data analysis and conclusion synthesis in sixth grade Life Science? This is a question I would like to help answer.

### Guiding Principles of the Study

The National Research Council (2002) formulated a set of guiding principles for scientific research in education that are essentially the same set of principles found across the entire spectrum of scientific inquiry. The following six principles for scientific research in education are interrelated but do not have to follow the order given below:

- (1) Pose significant questions that can be investigated empirically.
- (2) Link research to relevant theory.
- (3) Use methods that permit direct investigation of the question.
- (4) Provide a coherent and explicit chain of reasoning.
- (5) Replicate and generalize across studies.
- (6) Disclose research to encourage professional scrutiny and critique. (p. 52)

These are the principles which I will use guide my action research study. I have chosen a question that can be investigated empirically: can guided inquiry based labs improve the performance in data analysis and conclusion synthesis in 6<sup>th</sup> grade Life Science? I will link my research to relevant theory found in the literature. I will use the following methods: surveys,

an evaluation, laboratory exercises, inquiry assessments, and a chapter test. These will permit direct and indirect investigation of the question. I will provide a coherent and explicit chain of reasoning from my evidence to my conclusion. I will generalize my emerging themes, and I will publish my results.

### Assumptions

It is assumed that students participated fully and listened carefully during each laboratory exercise, chapter test and inquiry assessment, and completed them to the best of their ability. It is also assumed that students were honest and forthright in answering the science survey and class evaluation. The research-teacher assumes she gave adequate time to complete each assignment and provided the assistance that each student required.

### Limitations

The laboratory exercises, chapter test, inquiry assessment and final class evaluation were all prepared by the teacher-researcher, who attempted to write each item as clearly as possible so as to eliminate student misunderstanding. Student misunderstanding could skew the results of the study. The teacher-researcher performed all the grading as well as prepared and reported the results of the study. There was no second researcher to edit her study items or check her results.

Since the researcher was also their teacher, the students may have tilted their responses in the survey and final class evaluation more in favor of their teacher though they were encouraged to be completely honest. Students appeared to have no apprehension in participating in the study. Their only concern was they were not doing extra work. Their teacher-researcher assured them they would do nothing more than what was required of other students.

A concern of the teacher-researcher was that the students appeared to have had no prior knowledge of scientific inquiry procedures, and that this was their first experience with having to evaluate data and draw conclusions from data. The students required a great deal of support in the form of explaining inquiry procedures to help them to understand the inquiry process.

### Delimitations

This study was limited to a very small number of students: twelve to be exact. I recruited students from my three largest classes so as to obtain the widest possible assortment of student abilities. These students have abilities that vary greatly as demonstrated by their FCAT scores, which ranged from level 1 to level 5 with one student having documented learning disabilities. The small number of students made it easier to gather and evaluate data. The students and teacher were all located in a rural school, with limited resources.

### Definitions

According to an article written by Zimmerman (2007) the definition of scientific thinking is *the application of methods or principles of scientific inquiry to reasoning or problem-solving situations*. Scientific thinking also involves the process skills necessary to plan and execute experiments, analyze and interpret data, draw conclusions, formulate and revise theories. When fully developed, these scientific skills also include the ability to reflect on the process of knowledge acquisition and change. Children's scientific thinking involves the areas of conceptual formation and change, the development of reasoning skills and problem solving, and is the foundational pathway to skills needed to coordinate a complex mix of cognitive and

metacognitive abilities (Zimmerman, 2007).

Scientific inquiry as defined in the *Standards* refers to the diverse methods scientists use to study the natural world, and synthesize explanations for their observations based on the evidence derived from their work. Inquiry also refers to activities in which students develop knowledge and understanding of scientific ideas and methods scientists use to study the natural world (National Research Council, 1996). The National Research Council (1996) states:

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. (p. 23)

The inquiry method utilized was “the Five Es” as developed by the Biological Sciences Curriculum Study team in 1988 and described in an article by Robertson (2006/2007). This particular form of inquiry is called “guided inquiry” because the teacher guides or structures the learning experience so that students are exposed to an orderly learning process designed to clearly demonstrate the discoverable science concepts the students are to learn. This inquiry method can be described as having five steps: Engagement, Exploration, Explanation, Elaboration, and Evaluation. The laboratory exercise constituted the Engagement, Exploration and Explanation phases of this method while classroom instruction covered the remaining phases of Elaboration and Evaluation (Robertson, 2006/2007).

The *Standards* define science content in a broad context as “what students should know, understand, and be able to do in the natural sciences over the course of K – 12 education” (National Research Council, 1996, p. 6). The *Standards* specifically define Inquiry Standards for student achievement in grades five through eight as having the “Abilities necessary to do

scientific inquiry”, and possessing an “Understanding about scientific inquiry” (National Research Council, 1996, p.105). The *Standards* further define Life Science Standards for student learning in grades five through eight as being able to understand the following subject areas: “Structure and function in living systems”, “Reproduction and heredity”, “Regulation and behavior”, “Populations and ecosystems”, and “Diversity and adaptations of organisms” (National Research Council, 1996, p. 106).

Metacognition or thinking about one’s own thinking appears to be particularly important to the scientific thinking process observes the National Research Council (2007). Knowing a variety of cognitive strategies and being able to decide when, where and how to employ them during an investigation is very important in developing science process skills according to the National Research Council (2007). An awareness of one’s own limitations in knowledge, such as knowing the difference between opinion and evidence, is important in being able to reason within the scientific context of an investigation maintains the National Research Council (2007)

According to a book by Christmann and Badgett (2009), a correlation means there is a relationship between two variables: it does not show that one variable caused the other. The higher the numerical value of the correlation value, the stronger the relationship between two variables. A positive correlation shows a relationship between two variables, while a negative relationship shows that two variables are less likely have a relationship according to Christmann and Badgett (2009).

### Significance of Study

My action research studied the question “can inquiry based laboratory experiences improve the ability of sixth-grade Life Science students to analyze data and synthesize a



conclusion for their laboratory experience that explained what occurred during their experiment”. At the beginning and end of this study, student attitudes towards learning science were assessed using a survey designed by C.R. Pearce (Pearce, 1999). Students were assigned inquiry based laboratory exercises designed to complement the current topic being studied in class. The inquiry method utilized was a form “guided inquiry” called the “Five Es”. This inquiry methodology was used in my classroom due to the age, maturity level and science education experience of my sixth-grade students. The laboratory exercises provided the students with opportunities for engagement and exploration, while allowing them to analyze, evaluate, and explain their results Robertson (2006/2007) explained the “Five Es” in his article.

Vellom and Anderson (1999) maintain that the relationship between experience with phenomena, which is data observed or collected during laboratory experiments, and scientific theories is ignored as a goal in both the *Standards* of the National Research Council and another set of science education standards the AAAS *Benchmark*. Scientists are primarily engaged in a search for patterns that explain experimental or real world phenomena, and data collection serves as a means to this end. Vellom and Anderson (1999) also observe that both standards recognize the importance of the relationship between experience and theory in science and science learning, but only partially recognize the difficulty that can arise in data analysis and interpretation due to personal and cultural biases in the researcher.

This study attempted to examine in a small way this difficult subject of data analysis, laboratory experience, laboratory report conclusions, explanations of laboratory experiences, and scientific concepts. My hope is that this study will add a small piece of knowledge to the efficacy of inquiry based science instruction to improve science knowledge and the science

process skills of data analysis which is what the data tell the scientist, and conclusion synthesis which explains why the data and results occurred as they did. By increasing the body of knowledge in this area, school administrators will have more data available to enable them to make more informed decisions when deciding to change teaching methods and curriculums, and to select the best possible methods and curriculum in order to teach our children. This knowledge will also help me to better understand the needs of my own student population, and to adjust my practice to better serve my students and school.

### Summary

As previously detailed, the rationale behind this study is to explore the possibility that guided inquiry based science laboratory experiments can improve the ability of sixth-grade science students to analyze data and synthesize a conclusion that explains the phenomena or data they observed during the exercise. Inquiry based methods of teaching science are being touted by the National Research Council as the premier teaching method that will improve science literacy in the United States. The National Research Council (1996) maintains that science literacy is not only a necessity on a personal level but also on a national level since both the American culture and the World culture are now being driven technologically. A person must understand new scientific ideas and technology for the sake of not only one's health but to be able to obtain a job and function in an advanced technological society. An individual must be able to think critically and logically at all the choices that an advanced technological society makes possible and to choose the best course not only for oneself but for other members of one's family and society. The United States must obtain scientific literacy in order to compete globally so as to be able to provide for her citizens.

On a local level I will be undertaking this research to determine if guided inquiry based teaching methods as practiced in laboratory exercises and projects can specifically improve the science process skills in data analysis and formulating a conclusion in sixth-grade Life Science students in a rural middle school in the southern region of the United States. Course content and the order of instruction are mandated by the county to remain the same so that transient students get the same content at every school. Only the lab structure was changed to be inquiry oriented. All lab content followed county content and order of instruction.

The instrument used was a science survey formulated by Pearce (1999) to assess student attitudes towards science and learning science given both before the study began and after the study ended (Pearce, 1999). Other assessments used in the study were an inquiry method assessment designed by the teacher-researcher used to discover student knowledge of inquiry methods taken both before the study began and after the study ended, a chapter test designed by the teacher-researcher to measure content knowledge learned, and a final class evaluation designed by the teacher-researcher to measure the effectiveness of various classroom practices. The four guided inquiry laboratory exercises were taken from county laboratory exercises and modified to fit the guided inquiry method called the “Five E’s” (Robertson, 2006/2007). The following chapters will review the literature pertinent to this study and explain in detail the methodology utilized, the results obtained by this study, and the conclusions formulated concerning the outcome of this study.

## CHAPTER TWO: LITERATURE REVIEW

### Introduction

The report called the *National Science Education Standards* released in 1996 by the National Research Council through a branch committee known as the National Committee on Science Education Standards and Assessment provided the seminal information for the background and rationale for my study. The purpose of the *Standards* is to define science education standards for all students. The *Standards* are all about achieving both excellence and equity in science education for all students. Science is described by the *Standards* as more than a rote process during which students go through the motions of engaging in science and memorizing information. While no one curriculum is described in the *Standards*, one particular method is utilized most frequently. That teaching method is inquiry. The *Standards* use inquiry as their method of choice for achieving the twin goals of excellent science education and science literacy for all students in the United States (National Research Council, 1996).

### A Framework for Scientific Inquiry

I used the *Standards* definitions for inquiry and results. Inquiry entails actually working and thinking like a real scientist with students practicing scientific questioning and reasoning, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments and results to others so that their experiments can be duplicated to either prove or disprove the results (National Research Council, 1996).

An article written by Zimmerman (2007) provided me with a working definition of scientific thinking and a justification for including the development of scientific thinking as a goal of inquiry based instruction. Scientific thinking is defined as the application of methods or principles of scientific inquiry to reasoning or problem-solving situations. Scientific thinking also involves the process skills necessary to plan and execute experiments, analyze and interpret data, draw conclusions, formulate and revise theories. When fully developed, these scientific skills also include the ability to reflect on the process of knowledge acquisition and change. Children's scientific thinking involves the areas of conceptual formation and change, the development of reasoning skills and problem solving, and is the foundational pathway to skills needed to coordinate a complex mix of cognitive and metacognitive abilities. This article is a review of the literature at that time on the development of scientific thinking in both elementary and middle schools (Zimmerman, 2007).

Harmer and Cates (2007), who studied ways to engage learners in middle school scientific inquiry, have generalized the following principles concerning inquiry that could be applied across both content and grade levels in order to increase interest and engagement: (1) Select a real-world problem that could have many solutions. (2) A solution should have an immediate impact upon society. (3) Emphasis should be placed on the effect the problem has on students, family and friends. (4) Real-world researchers and scientists, who are currently working on a solution to the problem, should be contacted and involved if possible. (5) Give students many options and choices in working on a solution to the problem as a way to encourage their commitment. (6) Use technology to connect the resources of the outside world to classroom efforts. (7) Encourage students to work together on the solution to the problem. (8) Students

should receive encouragement and empowerment from the language used in classroom discussions and found in classroom materials. (9) Allow students to work on the solution on their own time outside of the classroom. (10) Tell students that their solution will be communicated to others in the outside world who are also working on the problem (Harmer and Cates, 2007).

According to the National Research Council (2000) in their book *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, inquiry teaching and learning have five fundamental requirements that apply across all grade levels:

(1) Learners are engaged by scientifically oriented questions. (2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions. (3) Learners formulate explanations from evidence to address scientifically oriented questions. (4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding. (5) Learners communicate and justify their proposed explanations. (pp. 24-27)

If all of the above five requirements are present in a lesson, then the lesson is said to be “full” or “open” inquiry. Most students, particularly younger ones, rarely have the abilities to successfully engage in full inquiry. Therefore the teacher may choose to structure, guide or coach the students in the inquiry process: this is called “partial” or “guided” inquiry. Students have to learn to ask scientifically oriented questions that can be investigated, learn the difference between evidence and opinion, learn how to formulate an explanation, and so on. A more structured or guided type of inquiry will develop a student’s ability to engage in more open inquiry (National Research Council, 2000).

Robertson (2006/2007) described the “Five Es” inquiry method as developed by the Biological Sciences Curriculum Study in his article. This inquiry method can be described as having five steps: Engagement, Exploration, Explanation, Elaboration, and Evaluation. The Five Es or 5E Instructional Model as it has been called is considered an inductive approach to learning

science by Chiappeta and Koballa (2006) because it provides students with learning situations where they can discover a scientific concept or principle in the laboratory, field or classroom. This type of approach provides students with a concrete experience from which they can obtain data. Students can use these data as a foundation upon which they can secure information and build new knowledge. This type of inductive activity is sometimes considered an experience-before-vocabulary approach to learning as explained by Chiappeta and Koballa (2006).

According to Llewellyn (2007) the 5E model moves students from concrete experiences to the development of understanding, and the application of the newly learned scientific concept or principle. During the Engagement stage, the teacher sets the stage for learning by introducing the topic and stating the purpose for the lesson. The teacher may also assess the students' prior knowledge. The Exploration stage allows the students to engage in inquiry where they may observe and collect data. During the Explanation stage, the teacher directs and facilitates data and evidence processing strategies. The teacher may also introduce more details, vocabulary and definitions about the lesson to help students put their thoughts into words and enable them to scientifically describe their experiences. In the Elaboration stage the teacher helps students extend their new found knowledge to new situations within the classroom or outside in the real world. The teacher brings closure to the lesson during the Evaluation stage by helping students summarize the relationships they discovered among the variables they investigated, and poses higher-order critical thinking questions to reinforce student learning as related by Llewellyn (2007).

Vellom and Anderson (1999) explained in their article that the relationship between experience with phenomena (data observed or collected during laboratory experiments) and

scientific theories is ignored as a goal in both the *Standards* (1996) and another set of science education standards the AAAS (1993) *Benchmark*s. Scientists are primarily engaged in a search for patterns that explain experimental or real world phenomena, and data collection serves as a means to this end. Vellom and Anderson (1999) also explain that both the *Standards* and the *Benchmarks* recognize the importance of the relationship between experience and theory in science and science learning, but only partly recognize the difficulty that can arise in data analysis and interpretation. My study attempted to examine in a small way this difficult subject of data analysis, laboratory experience, laboratory report conclusions and explanations of laboratory experiences, and scientific concepts. Vellom and Anderson (1999) provided the justification for my study.

### How Students Learn Science

The National Research Council (2005) has set forth three fundamental and well-documented learning principles as stated below:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
3. A “metacognitive” approach to instruction can help students learn to take control of their own learning by defining goals and monitoring their progress in achieving them. (pp. 1-2).

Zion, Michalsky and Mevarech (2005) found metacognitive guidance had a positive effect on learning in their study of scientific inquiry skills. The metacognitive guidance employed in their study consisted of two sets of metacognitive questions: metacognitive consciousness and executive questions. The metacognitive questions concerned problem-solving strategies,



assignment goals, the benefits of working in a group, and how the group helped in solving the inquiry problem. The executive questions helped students to control, monitor, and critique their cognitive processes and results. Both of these cognitive question sets helped students to reflect on their inquiry learning process by understanding and remembering the inquiry process (Zion et al., 2005).

Another critical insight into learning that the National Research Council (2005) observed is that “new understandings are constructed on a foundation of existing understandings and experiences” (National Research Council, 2005, p. 4). While this prior knowledge can serve to further the understanding of new information, it can also derail any new learning if the prior knowledge is erroneous as observed by the National Research Council (2005).

Rivet and Krajcik (2007) found a strong correlation in their study that supported the belief that contextualizing science education can improve science learning and lay a foundation for future learning. Contextualizing science education refers to using a student’s prior knowledge and life experiences to further their science learning, particularly in understanding difficult and complex science concepts. Contextualized instruction seeks to use current events or relevant situations that occur outside of the science class that are of personal interest to students, their local area or the world scientific community. These events serve to motivate and engage students in targeted science learning. Students may have either direct or indirect experiences with these events or situations (Rivet and Krajcik, 2007).

Palmer (2009) found in his study of student interest during inquiry that student interest remained high during the experimental phase when the inquiry investigation was being conducted by the students regardless of the subject being studied. Students showed moderate

interest during the hypothesis proposal stage and report writing or conclusion stage (Palmer, 2009). The main source of interest during the experiment phase was found to be physical activity, which Palmer (2009) postulated may have generated other stimuli such as social interaction, learning, variety or novelty, and personal autonomy as students made decisions during their investigations.

The National Research Council (2005) reports that both factual and conceptual knowledge are needed to support learning with understanding. Conceptual knowledge such a scientific theory or principle is a type of knowledge that is not likely to be learned in everyday life experiences. It usually requires time to be spent in the inquiry process to develop this knowledge. Many people often need help in understanding these complex scientific principles. The concept of learning with understanding has two parts: factual knowledge and conceptual knowledge as explained by literature from the National Research Council (2005). Factual knowledge must be embedded within a conceptual framework so that it can be understood within its context. Concepts develop meaning by using detailed explanations or representations that contain many explanatory or supporting facts. Neither factual knowledge nor conceptual understanding in and of themselves can produce competent performance. As concepts become meaningful in the contexts in which they are applied, the National Research Council (2005) asserts that learning with understanding can support knowledge application in new situations.

The National Research Council (2005) finds that while an expert may know and remember many more facts than a less knowledgeable person, the expert is able to remember more facts because he sees them as organized sets of ideas while the less knowledgeable person just sees the same facts as separate pieces of information. When concepts are used to organize facts stored in

the memory, memory is much more effective in retrieving and applying the facts. The memory of factual knowledge is improved by using conceptual knowledge to organize a framework of important details. Teaching for understanding requires that core concepts be organized into related sets of ideas much like the memory of an expert maintains the National Research Council (2005).

### Developing Scientific Reasoning in Children

Tytler and Peterson (2004) developed three models of scientific reasoning found in children: phenomenon-based reasoning, relation-based reasoning, and concept-based reasoning. The purpose of their study was to better understand scientific reasoning in elementary children engaged in open exploratory activities. By studying how a child approaches different types of exploratory activities and engages in different dimensions of scientific reasoning, Tytler and Peterson (2004) wanted to apply this knowledge to strategies which promoted scientific reasoning in the classroom.

In phenomenon-based reasoning as described by Tytler and Peterson (2004), the explanation and description are not distinguished. The purpose of the investigation is to look and see. Investigative interpretation is guided by what is seen in the data. The conclusion contains both opinions and interpretations, and evidence is written down. The subject is investigated randomly and relationships are not investigated. Contradictory evidence is ignored, denied or explained away. Explanations are not cross-checked for other possible rationalizations, and multiple phenomena are not attributed to other concepts. Phenomenon-based reasoning corresponds to the lowest level of scientific reasoning according to Tytler and Peterson (2004).

Tytler and Peterson (2004) explained relation based reasoning as identifying the relationships

between observables or assumptions rather than searching for a hidden cause. Investigative procedures in this type of reasoning tend to lean towards confirming the hypothesis and are uncritical. The explanation simply evolves from the data without analytical examination of the data. Tytler and Peterson (2004) explained that the purpose of this type of investigation is to arrive at a successful outcome rather than find the true cause for the phenomena that occurred during the investigation. This type of reasoning is considered to be inductive by Tytler and Peterson (2004).

In concept based reasoning, Tytler and Peterson (2004) describe the explanation as being centered on concepts that represent an underlying cause or deeper level of interpretation. The investigative process is guided by proving or disproving the hypothesis. Contradictory evidence and possible alternative explanations for experimental phenomena are acknowledged. Concept based reasoning is considered to be deductive in nature, and represents the highest level of scientific reasoning according to Tytler and Peterson (2004).

A study done by Amsel and Brock (1996) to assess the developmental differences in evidence evaluation between adults and children used two groups of children and two groups of adults. One group of children consisted of seventy-seven second and third graders while the second group consisted of eighty-five sixth and seventh graders. The adult groups consisted of thirty-six non-college educated adults and forty college students. Each of the groups was presented with four data sets about plants grown by four people. The plant data presented either had a perfect positive or a perfect zero correlation between the health of the plants and one variable, which was either present or absent. The study groups either believed that this variable aided plant health or had no effect upon plant health. The study found that the children were more greatly

influenced by prior beliefs and missing data than adults. Amsel and Brock (1996) found that the children appeared to be less uncertain about causative or non-causative variables when some of the data were missing. Children were also less likely to justify their conclusions based on evidence than adults according to Amsel and Brock (1996).

McNeill and Krajcik (2008) formulated an instructional model to aid teachers in developing scientific explanation skills in students that consisted of three parts. The first part is the claim, which is a conclusion concerning the problem to be investigated. The second part is the evidence, data collected, or observations made that support the claim. The third part is the reasoning the students use to justify their conclusion, which should be based upon scientific principles (McNeill and Krajcik, 2008). The authors discovered that when the rationale behind a scientific explanation was explicitly explained by the teacher, students could see why they needed to include evidence and reasoning to support their claim (McNeill and Krajcik, 2008).

#### How Students Reason from Data

Carey and Smith (1993) developed a model about understanding the nature of science with three levels of understanding that describe the development of scientific understanding in students. Students at Level 1 in their understanding of the nature of science cannot distinguish between ideas and activities such as experiments, which are used to formulate ideas. The student tries “it” to see if it works. The “it” could be an experiment, an idea, a thing, or even an invention. The “it” is undefined in the mind of the student (Carey and Smith, 1993). The student’s motivation is to do the activity and not to test the idea (Carey and Smith, 1993). The goal of students at this point is to discover facts and answers about science and to invent things according to Carey and Smith (1993). Students who reach Level 2 in their understanding of the

nature of science can now distinguish between ideas and experiments according to Carey and Smith (1993). The student's motivation at this level is to test the idea to see if it is right (Carey and Smith, 1993). Students at this point consider the idea a guess, which may or may not have to be revised or rejected depending upon the results of the experiment (Carey and Smith, 1993). The student's guess is not considered a prediction derived from a scientific theory, which the student may not understand at this point (Carey and Smith, 1993). Students at this Level do not fully comprehend that any revised guess or idea must include all of the data both old and new, and that if proven false, the idea or guess may have to be revised (Carey and Smith, 1993). Students at Level 3 can not only distinguish between ideas and experiments, but they are motivated to experiment in order to verify their ideas or explore new ideas (Carey and Smith, 1993). Students at this Level can now understand the relationship between the results of their experiment and the theories that led to their ideas or predictions (Carey and Smith, 1993). Level 3 students have developed their understanding of the nature of science. They now realize that scientific knowledge is cumulative and interconnected, and that the goal of science is to formulate even deeper explanations concerning the world around them (Carey and Smith, 1993).

Sandoval and Millwood (2005) sought to understand how students formulate explanations from the evidence discovered during inquiry investigations. Scientific explanations are central to finding answers and meaning in scientific investigations as well as discovering new relationships. Science educators need to make sure that students make the most logical arguments during their explanations, and support them with the most plausible evidence (Sandoval and Millwood, 2005). The authors discovered that student explanations suffer from two deficiencies: plausibility and transparency (Sandoval and Millwood, 2005). Students appear

to have difficulty in determining the viability of their explanations. Students also have difficulty in looking for deeper or hidden meanings and relationships in their data: they appear to take the occurrence of data at face value (Sandoval and Millwood, 2005).

In a study by Kanari and Millar (2004), the authors sought to investigate how students understand data and measurement, and the ways they reason from this data while undertaking a scientific inquiry process. The experiment used by Kanari and Millar (2004) contained two independent variables and one dependent variable. One independent variable covaried with the dependent variable while the other independent variable did not. Each group of students consisted of ten students aged ten, twelve and fourteen years of age with a total of sixty students.

Kanari and Millar (2004) found that students had more difficulty interpreting data from the non-covarying variable than the covarying variable because they took repeated measurements concerning the non-covarying variable as though they thought they had made a mistake in measurement when they came across an unexpected result. Unfortunately, Kanari and Millar (2004) found that the repeated measurements were not done systematically, and were sometimes not even recorded. Though students recorded the repeated measurements most of the time, they did not attempt to calculate an average value from these repeated measurements. In only two cases did students average in the repeated measurements. Sometimes the repeated measurement was used to replace an initial measurement. Kanari and Millar (2004) found students had forgotten they had already taken a measurement with certain values for the independent variable or had forgotten the outcome of their measurement in five cases.

Kanari and Millar (2004) found students in their study appeared to use selective reasoning in certain situations as they interpreted the data they collected. When investigating the independent

variable that covaried with the dependent variable, many students quickly identified the data trend where one variable increased steadily as the other variable also increased. These students based their conclusion on this trend. Unfortunately, the other independent variable did not covary with the dependent variable and so no clear trend was observed in its data as the students investigated. Kanari and Millar (2004) reasoned this was confusing the students and they proposed several scenarios to explain this anomaly: student ideas about the physical conditions of the experiment, problems with measuring equipment, and possible variations in the measurements when repeated measurements were taken. Kanari and Millar (2004) found most of the students who came to the wrong conclusion, where the two variables did covary when they did not, focused on the measurements that appeared to show covariance, and repeated measurements that did not show covariance. Kanari and Millar (2004) discovered these students either selectively recorded and replaced data values to support covariance, or selectively focused on only those repeat measurements that showed covariance.

Kanari and Millar (2004) found most students used the trend-focused data collection strategy when they changed the value of the independent variable in steps usually by increasing its value. The students then looked for a corresponding steady increase in the value of the dependent variable. Kanari and Millar (2004) discovered a small number of students used a difference-focused strategy by first looking for a difference in the dependent variable when both small and large values for the independent variable were used. This method was more efficient than the trend-focused data collection strategy. The students' selection of strategies may have resulted from the way science investigations were taught at their schools. To Kanari and Millar (2004), most students did not appear to repeat measurements as a way to check their variability. Kanari



and Millar (2004) thought students were either following a routine learned in science class or else were investigating an anomaly in the data trend.

Kanaria and Millar (2004) found students showed a basic competence in investigating the relationship between two variables where covariance can clearly be shown. Most students varied only one independent variable at a time while keeping the other independent variable constant. This ability may be due to the English National Curriculum which stresses practical investigations concerning the relationship between two variables at an early age. Unfortunately Kanari and Millar (2004) found this does not seem to instinctively enable students to intuitively deal with investigations where data trends are less obvious. Since students were not able to extend this ability to more challenging investigations, Kanari and Millar (2004) reasoned that students need to be taught how to handle investigations where variables do not covary and data trends are less obvious or non-existent.

Kanari and Millar (2004) found students have difficulty with the idea that all measurements are subject to error and variability even when nothing has changed. Differences in measurement can be accounted for by taking an average value of repeated measurements, and the variation within a set of measurements is a good indicator of how close the average value is to the true value. Students also need a more clear understanding of measurement, measurement variability, and how to handle error according to Kanari and Millar (2004).

The persistence of scientific misconceptions is another difficulty that arises when trying to understand scientific reasoning in children. An article by Hellden and Solomon (2004) explains these misconceptions do not go away easily, and may come from experiences that took place before the student started elementary school. According to Hellden and Solomon (2004) these

misconceptions seem to survive better than school-taught science ideas introduced later. Hellden and Solomon (2004) discovered both adults and children have at least two types of knowledge about any phenomena: life-world knowledge and abstract scientific knowledge. Life-world knowledge is gained from life experiences, while abstract scientific knowledge consists of scientific principles and theories. The authors suspect there may be more than one type of life-world knowledge. Despite educational practices, both types of knowledge may coexist separately within student minds according to Hellden and Solomon (2004). Since non-conscious and implicitly cued memories appear to remain stable over time, Hellden and Solomon (2004) suspect this may explain why these misconceptions persist, and defy both teaching and logic. Since unconscious prompting can by-pass semantic memory, Hellden and Solomon (2004) suggest teachers try to get students to recall correct answers concerning abstract scientific knowledge by giving students useful prompts rather than simply labeling student work wrong when life-world answers surface.

#### Developing Science Process Skills in Students

The National Research Council (2007) maintains most studies show many students develop science process skills with age, however this development is significantly influenced by prior knowledge, experience and instruction. Young students like to experiment but their experiments are not systemically structured and their observational and reasoning skills are not very good. Student may improve in their performance of science skills as they age, but this is not a uniform progress with either age or the individual according to the National Research Council (2007).

An article by Hanuscin and Park Rogers (2008) describes the development of the fundamental science skills of observation and inference in elementary school students. Students need to

develop these basic skills at an early age in order to devise explanations for phenomena.

Inference is a process of logical reasoning that allows a student or scientist to use observations and possibly prior knowledge to understand phenomena (Hanuscin and Park Rogers, 2008).

Young students do not understand the role inference plays in devising an explanation for a phenomenon. Many young students do not understand the difference between observation and inference, and must be taught to understand and employ these two skills by their teacher (Hanuscin and Park Rogers, 2008). In order for young students to learn these two skills and understand how they are used to develop scientific explanations, they need to have many opportunities to practice them and engage in discussions with other students and their teacher (Hanuscin and Park Rogers, 2008).

Bell and Linn (2000) found in their study of scientific arguments devised by middle school students that they construct explanations by using unique speculations. Some students devise more than one creative speculation for their scientific explanations of what occurred during an investigation, but few provide justification for their speculations (Bell and Linn, 2000). The researchers also have evidence that students engaged in the assimilation of scientific knowledge and the formulation of scientific arguments actually increase their understanding of the nature of science (Bell and Linn, 2000).

Metacognition or thinking about one's own thinking appears to be particularly important to the scientific thinking process observes the National Research Council (2007). Students may not realize the limitations of their own memories when it comes to being accurate and systematic in recording data, observations, procedures, and results according to the National Research Council (2007). Knowing a variety of cognitive strategies and being able to decide when, where and how

to employ them during an investigation is very important in developing science process skills according to the National Research Council (2007). An awareness of one's own limitations in knowledge, such as knowing the difference between opinion and evidence, is important in being able to reason within the scientific context of an investigation maintains the National Research Council (2007).

Prior knowledge can shape an investigative approach used in an inquiry in many ways, particularly if it concerns the plausibility of the investigation or prior experience relating to the investigation observes the National Research Council (2007). This knowledge can influence the formation of a hypothesis and how it is tested, as well as how the evidence is interpreted. Prior knowledge can determine how new evidence is evaluated, and whether or not data anomalies are noticed or even recorded according to the National Research Council, (2007). Students are less likely to have a reservoir of prior knowledge upon which they can draw reasons explains the National Research Council (2007).

Experience and instruction are critical in the development of a broad range of scientific skills as well as the degree of sophistication that students display in applying these skills in new situations according to the National Research Council (2007). It is critical for students to spend time doing science within a properly structured educational framework in order to learn science maintains the National Research Council (2007). This framework affects not only the science skills students develop, but also their ability to reason scientifically about the quality of evidence gathered during an investigation and how it is to be analyzed. Instructional support is also crucial in developing the ability to engage in experimental design, keep accurate records, handle data anomalies, and modeling phenomena asserts the National Research Council (2007).

Crawford (2006) discovered in her study that the success of a teacher in teaching science as inquiry was determined by the teacher's beliefs about pedagogy, student learning, schools, and the nature of inquiry in science. The planning of instruction was guided by the teacher's beliefs about teaching science as inquiry. Some teachers felt inquiry would not work with their students because the students were indifferent, more concerned about grades, or would not work hard. These beliefs hindered teachers in employing inquiry based practices when teaching science (Crawford, 2006). Another factor in a teacher's success with teaching inquiry may have been the teacher's expertise with the subject matter. Teachers who struggled with their subject content had less knowledge and depth in their subject from which to draw upon than teachers who were more knowledgeable in their field (Crawford, 2006).

Germann and Aram (1996) sought to study the science processes of recording data, analyzing data, drawing conclusions and providing evidence among seventh-grade students. They found that while over 75 % of their students successfully performed all three parts of the experiment and recorded their data in the data table, only 61 % percent actually completed all three parts of the experiment correctly. Germann and Aram (1996) attributed this result to several possible problems. Students may had difficulty in following procedural directions due to poor comprehension skills or possibly they were unaware of the need for accuracy in scientific experimentation. Students may have also felt they understood the required procedural steps despite failing to carefully read the procedure. It is possible that students may not have understood the necessary inquiry elements in the experiment such as having a control. Maybe students had difficulty recording their data in the data table, or did not understand the correct procedure for placing data in the table or even the necessity of recording data in the data table

according to Germann and Aram (1996).

Germann and Aram (1996) defined analyzing data as the ability to determine the relationship between the independent and the dependent variables so as to prove or disprove the hypothesis. In their study, only 31 % of the students were able to look at the data and the hypothesis, and decide what the data said about the hypothesis. Germann and Aram (1996) found the remaining 69 % of the students did not appear to have considered the hypothesis when analyzing the data.

According to Germann and Aram (1996) being able to draw a conclusion from the data consists of comparing the results predicted by the hypothesis to the actual results obtained from experimentation and then deciding if the experimental results were the same as the hypothesized results so as to prove or disprove the hypothesis. Slightly over 50 % of the students in their study understood that the conclusion should either prove or disprove the hypothesis based on the experimental results. According to Germann and Aram (1996), those students who analyzed their data with the hypothesis in mind also tended to include the hypothesis in their conclusion. Germann and Aram (1996) attributed this to students not being able to differentiate between theory and evidence and not being able to apply theory to evidence so they did not reference their hypothesis.

Metacognitive is defined as thinking deeply about one's own thinking (Michaels, Shouse and Schweingruber, 2008). Germann and Aram (1996) summarized their results in stating that students need to learn how cause and effect questions in science are answered, and that scientific inquiry is different from engineering inquiry. The authors also maintain that students need to be aware of the need for precision in both results and procedures though data will always contain some degree of variation. The science process skills of analyzing data, drawing conclusions and

providing evidence necessitate metacognitive skills that include the ability to apply theory to data in order to draw a conclusion, and to use data to justify their conclusions according to Germann and Aram (1996).

### Summary

In summary, the article by Tytler and Peterson (2004) supports the idea that children can engage in various types of scientific reasoning, while the articles by Kanari and Millar (2004) and Germann and Aram (1996) find that children can analyze data and synthesize conclusions with limitations in some instances. Kanari and Millar (2004) found that students seem to have difficulty handling unanticipated results and data. Both Kanari and Millar (2004) and Germann and Aram (1996) discovered that students have problems processing errors within data and often ignore them or explain them away. According to both Kanari and Millar (2004) and Germann and Aram (1996), students fail to realize the need for precision, accuracy and truthfulness while conducting experiments. Kanari and Millar (2004) discovered that students look for simplistic, obvious relationships among variables, and often fail to realize relationships that are less than straight forward.

Sandoval and Millwood (2005) found that student explanations of evidence occurring during scientific inquiries have two problems: plausibility and transparency. Students appear to be unable to determine the actual viability of their explanations being able to truly or accurately explain the occurrence of their data. Students also take the occurrence of data at face value and do not look into alternative explanations for data occurrence, nor do they look for hidden or deeper reasons for data occurrence.

Tytler and Peterson (2004) found three different types of scientific reasoning in children:

phenomenon-based reasoning, relation-based reasoning, and concept-based reasoning.

Students utilizing phenomenon-based reasoning simply want to “look and see” what is going on during their investigation and do not want to delve into discovering the scientific processes and principles that are producing their data. Students want successful experimental outcomes in relation-based reasoning, and often exclude or explain away any data anomalies that may disprove their hypothesis rather than critically analyzing their data. Concept-based reasoning is the highest form of scientific reasoning in children and occurs when children try to explain the occurrence of their experimental data using scientific principles and theories. These children critically examine and acknowledge data anomalies.

Germann and Aram (1996) found some students are not able to differentiate between theory and evidence, and are not able to apply theory to evidence to formulate a conclusion. Germann and Aram (1996) also found these students may not even mention proving or disproving their hypothesis when writing their conclusions. Hellden and Solomon (2004) discovered that students may have deeply ingrained misconceptions about scientific concepts that may taint their reasoning.

The National Research Council (2007) states that most studies show many students develop science process skills with age, however this development is significantly influenced by prior knowledge, experience and instruction. Student may also improve in the performance of science skills as they age, but this progress is not uniform with respect to either the age of the student or the individual according to the National Research Council (2007).

Zion et al. (2005) found that metacognitive guidance had a positive effect on student learning in their study of scientific inquiry skills. Rivet and Krajcik (2007) discovered that



contextualizing science education can improve science learning, and lay a foundation for future learning. Palmer (2009) found that student interest during the experimental phase remained high as the students actively engaged in inquiry. McNeill and Krajcik (2008) devised an instructional model to help teachers develop scientific explanations skills in students that included three parts: the claim, the evidence used to support the claim, and the reasoning used to justify the conclusion.

Carey and Smith (1993) developed a model to explain how students understood the nature of science. Students on the first level could not distinguish between ideas and experiments, and engaged in an activity to see if it worked and not to test an idea. Students on the second level could now distinguish between ideas and experiments, and engaged in an activity to test an idea. Students on level three could also distinguish between ideas and experiments, but they engaged in activities not only to test ideas but to explore new ideas. These students were able to understand the relationships between the results of their experiments and scientific theories, which they used to make predictions concerning outcomes of their experiments.

Hanuscin and Park Rogers (2008) describe the development of the fundamental science skills of observation and inference in their study of elementary school students. They found that students need to develop these two skills early in order to be able to formulate explanations for phenomena occurring during scientific investigations. Teachers need to explicitly explain the differences between these two skills and how to use them. Teachers also need to provide many opportunities for students to practice these skills and engage in discussions with classmates and themselves in order to train young minds to reason scientifically. Crawford (2006) discovered

that the success of a teacher teaching science depended on the teacher's expertise of the subject matter, and their beliefs about pedagogy, student learning, schools, and the nature of scientific inquiry.

## CHAPTER 3: METHODOLOGY

### Introduction

The purpose of this study was to determine if inquiry based science labs can improve the performance in data analysis and conclusion synthesis in sixth grade Life Science. I have had previous experience with inquiry based teaching methods while teaching a physical science course. While I felt the students enjoyed the hands-on science experiences that inquiry afforded them, I was not sure they were actually learning to think critically. I also observed that some students in the previous inquiry based course struggled with discovering the desired science concepts from the inquiry based course because the textbook and labs presented these concepts in a rather abstract manner through direct discovery with little in the way of explanation or guidance.

I decided to design and analyze a study that would blend what I felt to be the best of both worlds: students could have hands-on experience in inquiry based science labs and projects designed to teach them to think critically, and receive additional support and reinforcement for their inquiry based learning from a traditional science classroom, where science concepts were presented and explained in a more concrete manner. The inquiry based science labs and projects were used to teach the students to reason and think critically since they analyzed data and formulated conclusions based on their data. These two skills are stressed by the *Standards* as being crucial in developing an understanding of science concepts as well as being necessary in everyday life. The inquiry based labs and projects also served to engage and prepare the students for understanding the desired science concepts presented more concretely in the classroom.

### Design of the Study

My study examined the question “can guided inquiry based labs improve performance in data analysis and conclusion synthesis in sixth grade Life Science. My research can be classified as a form of action research. Action research can be thought of as a mixture of other more definitive types of research such as qualitative, quantitative, applied, evaluative, experimental and non-experimental research.

The guided inquiry method used in this study was “the Five Es” method as detailed by Robertson (2006/2007) in his article. It was developed by the Biological Sciences Curriculum Study. This method can be described as having five steps: Engagement, Exploration, Explanation, Elaboration, and Evaluation. The laboratory exercise constituted the Engagement, Exploration and Explanation phases of this method while classroom instruction covered the remaining phases of Elaboration and Evaluation (Robertson, 2006/2007).

During the Engagement phase the students were questioned during classroom discussion about their prior knowledge of the topic covered in lab. The Exploration phase was the actual laboratory experiment. During the lab students were given hands on experience designed to expose them to scientific concepts concerning the current topic studied in class. Students were required to collect and document data during the lab. The Explanation phase occurred after the lab when students engaged in discussing with their partners, classmates and teacher what occurred during their experiments. It was in these discussions that students talked about their analysis of their data and explained their reasoning behind their conclusions. The Elaboration phase occurred as students further discussed with their partners what occurred during their experiments, and tried to analyze the data in light of the guided questioning provided by the

laboratory report as well as the background information given by the teacher. Students then tried to put into words their data analysis and reasoning behind their conclusions. They attempted to apply the principles developed during the laboratory exercise to explain the results of their experiences. The Evaluation included the grading of the laboratory report and the chapter test over the material covered in class and lab. This particular inquiry based teaching methodology is a form of guided inquiry where the teacher guides or structures the learning experience so that students are exposed to an orderly learning process designed to clearly demonstrate the discoverable science concepts the students are to learn (Robertson, 2006/2007). The “Five Es” method was the inquiry methodology utilized in my classroom due to the age, maturity level and science education experience of my sixth-grade students.

According to an article by Cunningham (2008), an action researcher mainly utilizes both qualitative and quantitative research. Qualitative methods are used to collect and analyze data from questionnaires, observations, interviews and forms of subjective instruments, and then interpret the meaning of these data using concepts from established theory. Quantitative methods are used to statistically analyze and report numerically such data as test scores measuring learned knowledge and other instruments, which have been graded for correctness by the action researcher. According to Cunningham (2008) action research can be said to be a form of applied research because it is generally used to provide guidance to a solution for a particular problem or for improving a teaching practice. Because the action researcher is engaged in gathering and then analyzing data in order to evaluate the effectiveness of a strategy or intervention, they are said to be engaged in evaluative research. Cunningham (2008) considers action research to be experimental because it manipulates independent variables within the intervention so that the

researcher can study their effects upon the study's dependent variables. Since these variables are often complex and have many interwoven relationships, Cunningham (2008) observes that it is difficult to assess their relationships and draw conclusions about the effect of the strategy, which is a characteristic of non-experimental research.

Cunningham (2008) also states in her article that action research gives teachers a reproducible and systematic way to analyze their classroom teaching practices, decide if classroom goals have been met, and plan for future classroom strategies using the knowledge gained from the action research. Cunningham (2008) maintains that action research can be considered an attempt to understand the rationale behind teacher practices and to improve these practices within the confines of the classroom environment. Cunningham (2008) also maintains that action research serves as a bridge between research-generated pedagogy and the real-life classroom.

My study could be defined as "practical action research" according to Fraenkel and Wallen (2006) in their chapter on action research within their book. Fraenkel and Wallen (2006) defined practical action research as a study intended to address a specific problem within a classroom, school or other community. Fraenkel and Wallen (2006) identified the primary purpose of action research as improving teaching practice in the short term, and providing guidance and information on larger issues in the future. My personal goal in this study was to improve my own practice by better serving the perceived needs of my students and school.

### Setting

This study was conducted in a rural middle school located in the southeastern part of the United States. The study population sample consisted of a twelve sixth grade Life Science students of mixed abilities and academic levels. Their FCAT levels ranging from 1 to 5, with one

student having documented learning disabilities. The school district is large and contains many urban and rural schools. The school where the study was conducted was listed at the time of the study as an “A” school under the current standards of the state of Florida.

### Procedures

This study was started by giving the pre-science survey by Pearce (1999) (Appendix C) to the student subjects to assess their perceptions and attitudes towards science and science learning. The students were then given the pre-inquiry assessment (Appendix D) to determine their knowledge about inquiry, analyzing a given experiment, and synthesizing a conclusion. Since both the pre-inquiry assessment and post-inquiry assessment contained the same scenarios and questions but differed only by their title, only the general form was included in the Appendix. During the body of the study, the student subjects were given four laboratory exercises to complete. Each exercise was written and performed using the Five Es guided inquiry format. These four laboratory exercises covered four topics: diffusion (Appendix F), osmosis (Appendix G), cellular respiration (Appendix H), and cell membrane selectivity (Appendix I). These topics were taken from their unit of study on cellular processes. Upon completion of the chapter material, the students were given a chapter test on the material (Appendix J) to determine whether or not the students had indeed learned the content material. At the end of the study the student subjects were again given the post-science survey and a post-inquiry assessment. The student subjects were given a final class evaluation (Appendix E) to determine which classroom practices were most helpful to the students.

The inquiry assessment gave the students two hypothetical scenarios and asked the students to determine the following: the hypothesis, the control, the independent variable, the dependent

variable, the constants, how the data should be analyzed, what should the conclusion be, and can the experimental procedure be improved. The inquiry assessment was developed by the teacher-researcher. Due to the limitations of time and the inability of the students to complete the lengthy inquiry assessments, only the first problem was counted in both the pre-inquiry assessment and the post-inquiry assessment.

The laboratory exercises were strictly guided procedurally so that students would observe and learn the scientific principles involved. All laboratory exercises asked the students to determine a hypothesis concerning the phenomena to be studied based on given classroom and laboratory discussion. Materials and procedures were provided. Data tables were required on all experiments while some experiments also required bar graphs. Each lab contained questions to guide the students to discover the scientific principles involved. Each lab also required the students to provide guided data analysis and conclusion synthesis. Students worked in pairs on their experiments and so collaborated with their partners in not only doing the experiment but in writing up the laboratory exercise as well.

The laboratory exercise on diffusion allowed the students to study diffusion, which is the movement of various molecules (excluding water) from an area of high concentration to an area of low concentration. The students also studied equilibrium, which is a state of balance where molecules are equally dispersed throughout a medium. This experiment required students to record their data in an already prepared data table. They also had to complete drawings of what they observed during the experiment as well as complete a hypothetical drawing of tea dispersing through water. The students then answered some brief questions on what they observed. Students were required to complete an analysis of their experiment by relating the food coloring



dispersing through the water using to molecules diffusing through a cell membrane. They also had to explain if their hypothesis was true or false, and identify the independent and dependent variables, constants, and control. For the conclusion, students were required to explain in detail how the food coloring diffused through the water using their vocabulary words.

The laboratory exercise on osmosis allowed students to study osmosis or the diffusion of water, which is the movement of only water molecules from an area of high concentration to an area of low concentration. The students also studied equilibrium where the same number of water molecules are located inside a given area as well as outside that area. The subject studied was a Gummy Bear. This experiment required students to record their data in an already prepared data table. In addition to data, the students had to record their observations about observable changes in the Gummy Bear before and after soaking in water. They also had to calculate the percent change in mass and measurement of the Gummy Bear after it soaked in the water. The equations to determine this were given to the students and they were provided with simple calculators. The students had to plug in their data correctly and then correctly calculate the changes as percentages. Next the students had to graph their changes on a simple bar graph which they constructed. Lastly, the students had to analyze their data by explaining what happened to the Gummy Bear as it soaked and relate it to the process of osmosis. They also had to explain if their hypothesis was true or false, and identify the independent and dependent variables, constants, and control. Lastly, students were asked to form a conclusion about their experiment by explaining how osmosis occurred in the Gummy Bear using their vocabulary words.

The laboratory exercise on respiration allowed students to study respiration, which is the

breakdown of food molecules into simpler substances and the release of energy stored in the food. For this experiment the students observed yeast as they tried to respire sugar, fruit juices, and artificial sweeteners. In this lab the students had to prepare their own data tables and graphs. They next answered a series of questions on their experiment to determine which substance provided the most energy for the yeast by measuring the amount of carbon dioxide given off by the yeast. The students were then asked to analyze their experiment by telling which substance produced the most gas, the second most gas and the least gas. They were also asked if the control produced gas. Next they had to explain how yeast respiration was like human respiration. They also had to explain if their hypothesis was true or false, and to identify the independent and dependent variables, constants, and control. Lastly, students were asked to form a conclusion about their experiment by explaining how respiration occurred in the yeast using their vocabulary words.

For their last experiment, students studied the selectivity of the membrane surrounding an egg. This lab was done as a demonstration in each class due to the expense involved and the possible danger of infection due to handling raw eggs that had been left unrefrigerated for days. The students were given a prepared data table to record the egg's measurements and mass. Next they had to record observation notes of changes in the egg as it was soaked in vinegar, water and corn syrup. The students had to make two bar graphs to record the mass changes and circumference changes of the egg after it soaked in the various substances. Students had to answer four questions concerning what they observed during the lab, and then analyze the movement or non-movement of vinegar, water and corn syrup through the egg's membrane. They then had to relate this movement to the transport of various substances through a cell

membrane. They also had to explain if their hypothesis was true or false, and identify the independent and dependent variables, constants, and control. Lastly, students were asked to form a conclusion about their experiment by explaining what happened to the egg as it soaked in the vinegar, water and corn syrup using their vocabulary words.

The chapter test consisted of eight multiple choice questions, seven fill-in-the blank questions, and two short answer essays. The multiple choice and fill-in-the blank questions concerned themselves with the cellular processes, definitions, energy and process requirements, and end products of these processes. The first essay required them to compare and contrast respiration and fermentation, while the second asked them to explain how photosynthesis, respiration and fermentation were related. The chapter test was designed to check content material mastery.

The final class evaluation consisted of four parts. The first part was designed to determine how much help the students received from certain classroom activities. The second part was designed to determine how much help the class had given the student in learning science skills. The third part was designed to determine how much the student thought they had improved in understanding science concepts, the nature of science, the inquiry process, completing a laboratory process, the ability to think through a problem and increasing or diminishing their interest in science. The last part consisted of two questions: How much of what you learned in this class will you remember and use in other classes and life? Did this class make you want to continue in science and learn more about science?

The science survey (Appendix C) used by this research study was originally designed by Charles R. Pearce and published in his book *Nurturing Inquiry: Real Science for the Elementary*

*Classroom.* This survey measured student perceptions towards learning, science, science learning, the value of science learning, the best perceived method for the student to learn and the possible inclusion of other subjects into science. This survey was used to measure and document any changes in student perceptions since it was given before and after the start of the study (Pearce, 1999). Permission to use and alter the survey were given by Olivia Reed, the Permissions, Contracts, and Copyright Assistant at Heinemann Publishers.

### Methods of Data Collection

The qualitative data collection methods used in this study were a student survey done both before the study began and after the study was completed, and a final class evaluation done after the study was completed. The richest source of qualitative data was found in the science surveys and final class evaluation. The data collected from the survey were used to record and measure student perceptions and attitudes towards science and science learning. The data collected from the final class evaluation were used to measure the effectiveness of classroom activities and strategies used to aid students in learning. The quantitative instruments used in this study were an inquiry assessment given before the study began and after the study ended, a chapter or material content test, and four laboratory reports, which were graded.

Both the science surveys and the final classroom evaluation had their data correlated either positively or negatively to show a relationship between a given statement and an outcome. According to a book by Christmann and Badgett (2009), a correlation means there is a relationship between two variables: it does not show that one variable caused the other. The higher the numerical value of the correlation value, the stronger the relationship between two variables. A positive correlation shows a relationship between two variables, while a negative

relationship shows that two variables are less likely have a relationship according to Christmann and Badgett ( 2009).

The original science survey by Pearce was allowed to be modified by the publisher so that students would be forced to make a choice between agreeing with a given statement or disagreeing with a given statement. The current answers include “SA” for “Strongly Agree”, “A” for “Agree”, “D” for “Disagree” and “SD” for “Strongly Disagree”. These answers were assigned point values as follows: 4 points for “Strongly Agree”, 3 points for “Agree”, 2 points for “Disagree”, and 1 point for “Strongly Disagree”. This scoring system resulted in a positive correlation with a given statement that had a score of 3 points or greater, or a negative correlation with a given statement that had a score of 2 points or less. A neutral position was not allowed.

Each question on the first three parts of the final classroom evaluation had four possible answers for the student to select from: “Was of No Help”, “Was of Little Help”, “Helped a Lot”, and “Helped a Great Deal”. These answers were listed at the top of each section as headers to the question. Underneath each answer was a point value that the student circled to indicate his response to each question. The answer “Was of No Help” was assigned a value of 1 point, the answer “Was of Little Help” was assigned a value of 2 points, the answer of “Helped a Lot” was assigned a value of 3 points, and the answer of “Helped a Great Deal” was assigned a value of 4 points. This scoring method yielded a positive correlation to a given statement if the score was 3 points or greater, and a negative correlation to a given statement if the score was 2 points or less. A neutral position was not allowed.

The inquiry assessment was studied to see if students could determine some of the necessary

elements included in an inquiry procedure such as determining the question asked by the researcher, the identity and nature of the independent and dependent variables, the presence or absence of constants and controls and their value to the experiment, the ability to analyze given data and synthesize a conclusion, and tell if any modifications need to be made to the experiment to improve its reliability.

Laboratory exercises were considered examples of actual student classroom work and were collected to assess student learning of both the material content and the inquiry process, and to observe any development in scientific reasoning and science process skills. The laboratory exercises were graded for correctness and the desired learning of the scientific principles demonstrated in the exercises. Laboratory exercises were given grades in the form of point values according to the standard grade scale in my county where an “A” grade ranges from 100 points to 90 points, a “B” grade ranges from 89 points to 80 points, a “C” grade ranges from 79 points to 70 points, a “D” grade ranges from 69 points to 60 points, and a failing grade of “F” ranges from 59 points to 0 points.

The chapter test was given at the end of the material chapter and graded for correctness and the desired material answers on the essays. The test was worth 100 points, with the multiple choice part and fill-in-the-blank part questions worth 6 points each. The essay questions were worth 5 points each, and partial credit was given. The standard county grading scale as defined above was used to assign grades for test.

#### Methods of Data Analysis

All data collected on material content and inquiry methodology were assessed according to the county order of instruction, the Florida Sunshine State Standards and the National Science

Education Standards for grades five through eight to determine if students were learning content, and developing the ability to analyze data, synthesize a conclusion and rationalize an explanation for phenomena occurring during lab. Students with grades of either a “D” or an “F” were given remediation exercises and extra help from the teacher to correct their deficiencies.

Quantitative data were analyzed as follows. The chapter test and laboratory exercises were scored by the researcher and documented both as study results and student grades. The school used the standard grading scale of 100 % to 90 % as being an “A”, 89 % to 80 % as being a “B”, 79 % to 70 % as being a “C”, 69 % to 60 % as being a “D”, and 59 % or lower as being an “F”.

These various data were triangulated to see if emerging themes occurred in learning, content learning, data analysis, conclusion synthesis, and reasoning abilities throughout the various methods employed. Student perceptions about learning, ways of learning, thinking, classroom activities that may help in learning and competency in certain skills were assessed and triangulated using the Pre-science survey, Post-science survey, and final Classroom Evaluation. Student learning of content material was assessed and triangulated using the inquiry assessment, chapter test, and laboratory reports. Student ability in analyzing data and synthesizing a conclusion based upon their explanations of phenomena occurring during the experiment were assessed and triangulated using the inquiry assessment, student laboratory reports, and the chapter test.

The findings are discussed more thoroughly in Chapter Four. Here the data are correlated to prove the emerging themes, the learning of content material, the ability to analyze data, and the ability to synthesize a conclusion.

## CHAPTER 4: RESULTS

### Introduction

This study was conducted during late fall of 2008 and early winter of 2009 to see if inquiry-based laboratory exercises could improve the performance of 6<sup>th</sup> grade Life Science students in the science process skills of data analysis and conclusion synthesis. Data representing student performance in the science process skills of data analysis and conclusion synthesis were collected. Data were also collected on student attitudes and perceptions of both the inquiry process and learning process. Action research was the type of model used by the researcher, which can be a useful tool in ascertaining the value of current teaching methods.

The data from the science surveys, inquiry assessments, laboratory exercises, chapter test and final class evaluation were read and analyzed to detect emerging themes and to ascertain whether or not the research question was answered. The results of this study were quantified statistically using positive and negative correlations and percentages, though the methods of data analysis and interpretation were more qualitative.

### Emerging Themes

The first four generalized emerging themes relate indirectly towards answering the research question because they are important as a way of showing that the inquiry process is helping students to learn and become interested in their own learning. These first four emerging themes were taken from positive correlations displayed by data collected from the pre-science survey and post-science survey. According Christmann and Badgett (2009), a correlation means there is a relationship between two variables: it does not show that one variable caused the other. The



higher the numerical value of the correlation value, the stronger the relationship between two variables. A positive correlation shows a relationship between two variables, while a negative relationship shows that two variables are less likely have a relationship according to Christmann and Badgett (2009). The fifth generalized and last relevant emerging theme came from part 3 of the final class evaluation, and leads directly towards answering the research question: can guided inquiry based labs improve the performance in data analysis and conclusion synthesis in sixth grade life science? The fifth generalized emerging theme says that students gain confidence and competency by doing inquiry. Together these relevant emerging themes are: students are learning from the guided inquiry process, students learn more from the inquiry process than by having someone tell them the facts, students are learning to think, students learn more by working with others, and students gain confidence and competency by doing inquiry.

The first generalized relevant emerging theme of students learning from the guided inquiry process is taken from the positive correlations found in both the pre-science survey and post-science survey where students responded to the statements that learning is finding out about things that interest the student, and discovering answers to student generated questions is interesting. This information is found in Tables 1, 2 and 3 on the following pages. This theme is also corroborated in part 1 of the final class evaluation found on Table 7 where students displayed a positive correlation in responding to the statements that they received more help in learning when doing hands-on labs and in the way that the class was taught, which was guided inquiry. A positive correlation to student learning in the way the class was taught using guided inquiry helps to confirm Crawford (2006), who maintained that a teacher's beliefs about pedagogy, schools, student learning and the nature of inquiry in science teaching were critical in

a teacher's success in teaching inquiry.

Students also displayed a positive correlation to the teacher showing examples and explaining. This supports the findings of McNeill and Krajcik (2008) which specify that when the scientific explanation was explicitly explained by the teacher, students could see why they needed to include evidence and reasoning to support their claims. It also supports the findings of Hanuscin and Park Rogers (2008) that students need to understand and know how to employ observation and inference, two fundamental science skills that are necessary in order to analyze data and draw conclusions. Hanuscin and Park Rogers (2008) also found that students need to be taught to understand and apply these two skills. This is also corroborated in both the pre-science survey and post-science survey found on Tables 1, 2, and 3 in the following pages when students displayed a negative correlation when asked if they learned more from reading than doing.

The second generalized relevant emerging theme of students learning more from the inquiry process than by having someone tell them the facts is corroborated by the negative correlation students displayed in part 1 of the final class evaluation found in Table 7 when asked if they learned from teacher lectures. This supports the finding of Bell and Linn (2000) that students engaged in the assimilation of scientific knowledge and the formulation of scientific arguments actually increase their understanding of the nature of science. This is again corroborated in part 1 of the final class evaluation found in Table 7 where a weak negative correlation of 2.1 is displayed by students when asked if they received help in learning by reading the textbook. This emerging theme is also corroborated in part 3 of the final class evaluation found on Table 9 where students displayed a positive correlation to receiving help in the class in understanding the main concepts in science as well as understanding the nature of science.

The third generalized emerging theme of students learning to think is corroborated in part 3 of the final class evaluation found on Table 9 where students displayed a positive correlation to receiving help in class in acquiring the ability to think through a problem or question. They also displayed positive correlations in part 3 of the final class evaluation found in Table to understanding the parts of an inquiry process, understanding how inquiry is done, and learning how to complete an inquiry process. Inquiry within itself is a thinking process as well as an action process. This emerging theme supports the findings of Zion et al. (2005) that metacognitive guidance employed within inquiry has a positive effect upon learning. Thinking about and analyzing the inquiry process itself leads to enhanced knowledge of the inquiry process (Zion et al., 2005).

The fourth generalized emerging theme of students learning more when working with others is corroborated in part 1 of the final class evaluation where students displayed the highest positive correlation to working with lab partners as a way of learning. This is also corroborated in both the pre-science survey and post-science survey when students displayed a negative correlation when asked if they learned more when they worked alone. This also supports a finding of Hanuscin and Park Rogers (2008) that in order for young students to learn observation and inference skills and understand how they are used to develop scientific explanations, they need to have many opportunities to practice them and engage in discussions with other students and their teacher.

The fifth generalized emerging theme of students gaining confidence and competency by doing inquiry is taken from part 2 of the final class evaluation found in Table 7 where students displayed positive correlations to the following statements: feeling confident they can do a lab

and get results, making lab observations, writing a lab analysis, writing a lab hypothesis, and writing a lab conclusion. This emerging theme is corroborated by post-inquiry assessment found on Table 10 where students proved they could successfully formulate a relevant hypothesis, successfully identify a control, and successfully identify the independent variable 100 % of the time. Students also proved that they could successfully identify both the dependant variable and constants as well as successfully formulate both a relevant conclusion and a relevant data analysis 88 % of the time. These results support the findings of the National Research Council (2007) that knowing a variety of cognitive strategies and being able to decide when, where and how to employ them during an investigation is very important in developing science process skills

#### Data and Analysis of Student Science Surveys

Specific emerging themes from the pre- and post-science surveys found on Tables 1, 2, and 3, suggest that students: think about what they are thinking (metacognition), learn more if they have a choice about what they are learning, find discovering answers to their own questions interesting, define learning as finding out about things that interest them, do not think they can learn more from reading than doing, and think that facts discovered on their own are more memorable than facts someone else tells them. Other specific emerging themes found on Tables 3, 4, and 5 are: students understand more if they can talk it over with a partner, learn more when they work in a group and share ideas, and like to discuss what they have learned. Both surveys displayed a negative student response correlation to the statement that I learn more from reading than doing.

Table 1: Pre-Science Survey of Student Perceptions about Inquiry Learning

Statements	Pre-science survey				Average Correlation
	Strongly Agree	Agree	Disagree	Strongly Disagree	
11. Learning is finding out about things that interest me.	3	6	1	0	3.2
3. As I learn it is important to think about my thinking.	2	8	0	0	3.2
7. Discovering answers to my own questions is interesting.	2	7	1	0	3.1
16. Science textbooks are the best books to read to learn about science.	2	5	3	0	2.9
2. I learn best by reading chapters and answering questions.	2	4	4	0	2.8
19. Facts I discover on my own are more memorable than facts someone else tells me.	3	4	1	2	2.8
4. I learn more if I have a choice about what I am learning.	1	5	1	3	2.4
18. I can learn more by reading than doing.	0	2	5	3	1.9

Strongly Agree=4, Agree=3, Disagree=2, Strongly Disagree=1. Survey was completed by 10 students.

Table 2: Post-Science Survey of Student Perceptions about Inquiry Learning

Statements	Post-science survey				Average Correlation
	Strongly Agree	Agree	Disagree	Strongly Disagree	
4. I learn more if I have a choice about what I am learning.	7	3	2	0	3.3
19. Facts I discover on my own are more memorable than facts someone else tells me.	3	6	2	0	3.1
11. Learning is finding out about things that interest me.	3	6	3	0	3.0
3. As I learn it is important to think about my thinking.	5	3	3	1	3.0
7. Discovering answers to my own questions is interesting.	1	8	1	2	2.7
2. I learn best by reading chapters and answering questions.	1	4	6	1	2.4
16. Science textbooks are the best books to read to learn about science.	1	5	4	2	2.4
18. I can learn more by reading than doing.	0	3	4	5	1.8

Strongly Agree=4, Agree=3, Disagree=2, Strongly Disagree=1. Survey was completed by 12 students. On Statement 19, one student did not answer so they were not counted on this question.

Student importance associated with certain responses changed from the pre-science survey found on Table 1 to the post-science survey found on Table 2. The statements in the pre-science survey with the most positive correlations were 11, 3, and 7: all with correlations above 3. The statements with the most positive correlations in the post-science survey were 4, 19, 11, and 3: all with correlations above 3. Statements 11 and 3 decreased from a positive correlation in the

pre-science survey to a less positive correlation in the post-science correlation. Statement 7 decreased from a positive correlation in the pre-science survey to a negative correlation in the post-science survey. Statements 2 and 16 decreased from negative correlations in the pre-science survey to even more negative correlation in the post-science survey. Statements 4 and 19 increased from negative correlations in the pre-science survey to positive correlations in the post-science survey. The guided inquiry process appears to have stimulated students to desire a choice in what they are learning, and discovering facts on their own has become much more important to them. The principles generated by Harmer and Cates (2007) have meaning as shown by the post science survey. Students are encouraged, empowered and stimulated, and much more interested in scientific inquiry when they are actively involved in discovering their own answers and making choices in that discovery. Table 3 displays both the pre-science and post-science survey results side by side to make it easier to view these changes.

Table 3: Pre-and Post-Science Surveys of Student Inquiry Learning

Ranked Pre-Science Survey Statements	Corresponding Pre-Science Survey Average Correlations	Ranked Post-Science Survey Statements	Corresponding Post-Science Survey Average Correlations
11. Learning is finding out about things that interest me.	3.2	4. I learn more if I have a choice about what I am learning.	3.3
3. As I learn it is important to think about my thinking.	3.2	19. Facts I discover on my own are more memorable than facts someone else tells me.	3.1
7. Discovering answers to my own questions is interesting.	3.1	11. Learning is finding out about things that interest me.	3.0
16. Science textbooks are the best books to read to learn about science.	2.9	3. As I learn it is important to think about my thinking.	3.0
2. I learn best by reading chapters and answering questions.	2.8	7. Discovering answers to my own questions is interesting.	2.7
19. Facts I discover on my own are more memorable than facts someone else tells me.	2.8	2. I learn best by reading chapters and answering questions.	2.4
4. I learn more if I have a choice about what I am learning.	2.4	16. Science textbooks are the best books to read to learn about science.	2.4
18. I can learn more by reading than doing.	1.9	18. I can learn more by reading than doing.	1.8

Tables 4 and 5 demonstrate the fact that students prefer to work with a partner, learn more when they are able to talk things over with a partner and share ideas, and like to discuss what they have learned. Tables 4 and 5 also show that students do not learn more when they work alone.



Table 4: Pre-Science Survey of Student Perceptions about Working with Others

Statements	Pre-science survey				Average Correlation
	Strongly Agree	Agree	Disagree	Strongly Disagree	
5. When I talk things over with a partner, I understand more about what I am learning.	3	7	0	0	3.3
6. I learn more when I work in a group and share ideas.	4	5	1	0	3.3
10. I like to discuss what I have learned.	2	6	2	0	3.0
9. I learn more when I work alone.	0	0	7	3	1.7

Strongly Agree=4, Agree=3, Disagree=2, Strongly Disagree=1. Survey was completed by 10 students.

Table 5: Post-Science Survey of Student Perceptions about Working with Others

Statements	Post-science survey				Average Correlation
	Strongly Agree	Agree	Disagree	Strongly Disagree	
6. I learn more when I work in a group and share ideas.	5	6	1	0	3.3
5. When I talk things over with a partner, I understand more about what I am learning.	4	7	0	1	3.2
10. I like to discuss what I have learned.	3	6	1	2	2.8
9. I learn more when I work alone.	0	0	9	3	1.8

Strongly Agree=4, Agree=3, Disagree=2, Strongly Disagree=1. Survey was completed by 12 students.

The correlations of student perceptions when working with others and working alone did not change between the pre-science survey and the post-science survey as shown on Tables 4 and 5. Student rankings of these statements did not change either as shown on Table 6. Students appear to be certain that they learn more when working with others.

Table 6: Pre-and Post-Science Surveys of Student Perceptions about Working with Others

Statements	Pre-science survey Average Correlations	Post-science survey Average Correlations
6. I learn more when I work in a group and share ideas.	3.3	3.3
5. When I talk things over with a partner, I understand more about what I am learning.	3.2	3.2
10. I like to discuss what I have learned.	2.8	2.8
9. I learn more when I work alone.	1.8	1.8

#### Data Analysis of the Final Class Evaluation

The specific emerging themes from the final part 1 classroom evaluation as shown on Table 7 suggest that the following classroom activities showed a higher positive correlation in helping students learn: working with lab partners and hands on labs. The teacher showing examples and explaining, and the way class was taught also showed a positive correlation though less so than the above mentioned activities. Teacher notes, worksheets and reading the textbook showed a negative correlation in student perceptions of what helps them learn. Teacher lectures showed the most negative correlation in student perceptions of helping them learn.

Table 7: Class Evaluation of Student Perceptions about Help Received in Class Activities

Statements	Final Class Evaluation				Average Correlation
	Helped a Great Deal	Helped a Lot	Little Help	No Help	
6. Working with Lab Partners	8	3	0	0	3.7
4. Hands-on Labs.	7	3	0	1	3.5
8. Teacher showing examples and explaining.	3	6	2	0	3.1
10. The way class was taught.	2	8	1	0	3.1
1. Teacher Notes.	3	8	0	0	2.5
7. Work Sheets.	0	4	6	1	2.3
3. Reading Textbook.	0	1	10	0	2.1
2. Teacher Lectures.	0	1	6	3	1.8

Helped a Great Deal=4, Helped a Lot=3, Little Help=2, No Help=1. Evaluation was completed by 11 students. On Statement 2, one student did not answer so they were not counted on this question.

The specific emerging themes of part 2 of the final class evaluation as found on Table 8 demonstrated a more positive correlation to classroom learning are: making lab observations, feeling confident the student can do a lab and get results, and understanding what the data are showing the student. The following statements concerning writing a lab analysis, writing a lab hypothesis, and writing a conclusion showed a negative correlation to classroom learning.

Table 8: Class Evaluation of Student Perceptions about Help Received in Learning Skills

Statements	Final Class Evaluation				Average Correlation
	Helped a Great Deal	Helped a Lot	Little Help	No Help	
4. Making Lab Observations.	5	4	2	0	3.6
8. Feeling confident I can do a lab and get results.	5	4	2	0	3.6
7. Understanding what the data were showing me.	4	5	1	0	3.3
2. Writing a lab analysis.	2	3	3	3	2.4
1. Writing a lab hypothesis.	2	2	5	2	2.4
3. Writing a lab conclusion.	2	3	5	1	2.3

Helped a Great Deal=4, Helped a Lot=3, Little Help=2, No Help=1. Evaluation was completed by 11 students. On Statement 7, one student did not answer so they were not counted on this question.

The specific emerging themes of part 3 of the final class evaluation as found on Table 9 are shown by a positive correlation to classroom learning to the following statements: ability to think through a problem or question. The statements concerning about understanding the main concepts in science, understanding the nature of science, understanding the parts of an inquiry process, completing an inquiry process or lab, and understanding how inquiry is done all showed weak negative correlations to classroom learning in these areas. This appears to support the three levels of understanding the nature of as proposed by Carey and Smith (1993). Students at Level 1 and 2 of the Carey and Smith (1993) model have difficulty understanding the nature of science, science theories, the reason for performing experiments, and utilizing a science theory in order to

make a prediction or structure an experiment.

Table 9: Class Evaluation of Student Perceptions about Help Received in Improving Tasks

Statements	Final Class Evaluation				Average Correlation
	Helped a Great Deal	Helped a Lot	Little Help	No Help	
6. Ability to think through a Problem or Question.	4	4	2	1	3.0
1. Understanding main concepts in science.	4	1	6	0	2.8
2. Understanding the nature of science.	3	3	4	1	2.7
4. Understanding the parts of an inquiry process.	3	2	5	1	2.6
5. Completing an Inquiry Process or Lab.	1	5	4	1	2.5
3. Understanding how Inquiry is done.	1	4	4	2	2.3

Helped a Great Deal=4, Helped a Lot=3, Little Help=2, No Help=1. Evaluation was completed by 11 students.

### Data Analysis of the Inquiry Assessments

Table 10 shows the data from both the pre-inquiry assessment and the post-inquiry assessment. On the pre-inquiry assessment 72 % of the students were able to formulate a hypothesis of the problem and identify the control in the problem. While 36 % of the students could identify both the independent variable and the dependant variable in the problem, and formulate a relevant conclusion for the problem. Only 9 % of the students could identify the constants in the problem and formulate a relevant data analysis for the problem.

On the post-inquiry assessment 100 % of the students were able to formulate a hypothesis of the problem, and identify both the control and the independent variable in the problem. Most of the students, 88 %, could identify both the independent variable and constants in the problem, and formulate both a relevant conclusion and data analysis for the problem.

Table 10: Pre-and Post-Inquiry Assessments of Student Inquiry Learning in Problem Solving

Inquiry Processes	Pre-Inquiry Assessment Percentages	Post- Inquiry Assessment Percentages
Successfully formulating a relevant hypothesis about the problem.	72	100
Successfully identifying the control.	72	100
Successfully identifying the independent variable.	36	100
Successfully identifying the dependant variable.	36	88
Successfully formulating a relevant conclusion of the problem.	36	88
Successfully identifying the constant(s).	9	88
Successfully formulating a relevant analysis of the problem data.	9	88

Number of students taking the pre-inquiry assessment was 11, while number of students taking the post-inquiry assessment was 9.

#### Analyzing the Laboratory Exercises

Table 11 shows the results for the lab exercises. For the diffusion laboratory exercise: 100 % of the students were able to formulate a hypothesis, 90 % of the students were able to formulate a

correct data analysis, 100 % of the students were able to formulate a correct conclusion, and 100 % of the students could correctly state the scientific principle involved. After the laboratory exercise on osmosis: 92 % of the students were able to formulate a hypothesis, 66 % of the students were able to formulate a correct data analysis, 75 % of the students were able to formulate a correct conclusion, and 90 % of the students could correctly state the scientific principle involved. For the respiration laboratory exercise: 100 % of the students were able to formulate a hypothesis, 82 % of the students were able to formulate a correct data analysis, 73 % of the students were able to formulate a correct conclusion, and 82 % of the students could correctly state the scientific principle involved. On the last laboratory exercise which was on the selectivity of a cell membrane: 100 % of the students were able to formulate a hypothesis, 87 % of the students were able to formulate a correct data analysis, 75 % of the students were able to formulate a correct conclusion, and 75 % could correctly explain the scientific principle involved.

The analysis of the lab exercises appears to support the findings of Rivet and Krajcik (2008) that utilizing prior knowledge and the everyday life experiences of students serves as a springboard for understanding complex science concepts. With the exception of drawing a conclusion on the osmosis lab, students successfully demonstrated their mastery of formulating a hypothesis, analyzing data, formulating a conclusion and successfully completing the lab exercise.

Table 11: Analysis of Inquiry Processes Required in Lab Exercises

Inquiry Lab Process	Percentages			
	Diffusion Lab	Osmosis Lab	Respiration Lab	Cell Membrane Selectivity Lab
Successfully formulated a relevant hypothesis.	100	92	100	100
Successfully demonstrated understanding of science concept by successfully completing lab exercise.	100	90	82	75
Successfully formulated a relevant conclusion.	100	75	73	75
Successfully formulated a relevant analysis of the data.	90	66	82	87

Number of students completing each Lab was 10 for the Diffusion Lab, 12 for the Osmosis Lab, 11 for the Respiration Lab and 8 for the Cell Membrane Simulation Lab.

#### Data Analysis of the Chapter Test

The analysis for the chapter test as shown in Table 12 is as follows: 92 % of the students got question one correct which represented cell membrane selectivity, 92 % of the students got question twelve correct which represented diffusion, 92 % of the students got question fourteen correct which represented osmosis, and 92 % of the students got question ten correct which represented respiration. The 92 % represents the fact that eleven out of twelve students responded correctly to these questions. The 8 % represents one student out of twelve students that responded incorrectly to these questions.

The analysis of the chapter test also appears to support the findings of Rivet and Krajcik (2008) that utilizing prior knowledge and the everyday life experiences of students serves as a springboard for understanding complex science concepts. Students answered the questions on



diffusion, osmosis, respiration and cell membrane selectivity correctly 92 % of the time.

Table 12: Analysis of Test Questions Relating to Science Concepts in Labs

Inquiry Processes	Percentage Answering Correctly	Percentage Answering Incorrectly
Diffusion.	92	8
Osmosis.	92	8
Respiration	92	8
Cell Membrane Selectivity	92	8

Number of students taking the test was 12.

#### Learning to Analyze Data

The results of the pre-inquiry assessment, post-inquiry assessment, laboratory exercises, and chapter test suggest that students are learning to analyze their data. Most students appeared to grasp the science process skill of analyzing data. This was indirectly supported by the fact that students displayed a positive correlation in the final class evaluation that showed the class helped them to learn to think through a problem. It was also indirectly supported in the post-inquiry assessment where 100 % of the students could correctly formulate a hypothesis on the problem. Another indirect proof was that between 100 % and 92 % of the students could formulate a hypothesis on all four laboratory exercises. In order to analyze data you must know the question you are seeking to prove or disprove. Student acquisition of this skill was also directly supported by the fact that 88 % of them could formulate a relevant data analysis of the problem on the post-

inquiry assessment. An even more direct support for the acquisition of this skill was that on the four laboratory exercises: 90 % of the students could formulate a relevant analysis of the data in the diffusion lab, 66 % of the students could formulate a relevant analysis of the data in the osmosis lab, 82 % of the students could formulate a relevant analysis of the data in the respiration lab, and 87 % percent of the students could correctly formulate a data analysis on the cell membrane selectivity lab.

#### Learning to Synthesize Conclusions

The results of the pre-inquiry assessment, post-inquiry assessment, laboratory exercises, and chapter test also suggested that students are learning to formulate a conclusion. Most students appeared to grasp the science process skill of synthesizing conclusions. This was indirectly supported by the fact that they stated in the final class evaluation that the class helped them to learn to think through a problem. It was also indirectly supported in the post-inquiry assessment where 100 % of the students could correctly formulate a hypothesis the problem. In order to analyze data and synthesize a conclusion, you must know the question you are seeking to prove or disprove. Another indirect proof was that between 92 % and 100 % of the students could formulate a hypothesis on all four laboratory exercises. Student acquisition of this skill was more directly supported by the fact that 88 % of them could formulate an analysis of the problem on the post-inquiry assessment. An even more direct support for the acquisition of this skill was that on the four laboratory exercises 100 %, 75 %, 73 % and 75 % of the students could correctly synthesize a conclusion on their lab reports.

### Learning Content Material

Most students appeared to learn the county and state mandated content material for cellular processes. This was directly supported by the fact that ninety-two percent of the students got all four questions concerning cell membrane selectivity, diffusion, osmosis and respiration correct on the chapter test. Another direct support for content learning was that on the four laboratory exercises one hundred percent, ninety percent, eighty-two percent and seventy-five percent of the students could correctly explain the scientific principles involving cell membrane selectivity, diffusion, osmosis, and respiration.

## CHAPTER 5: CONCLUSIONS

### Introduction

The focus of this study was to determine whether or not the use of guided inquiry based labs can improve the performance in analyzing data and conclusion synthesis in 6<sup>th</sup> grade Life Science. The cellular processes of diffusion, osmosis, respiration, and cell membrane selectivity were studied in lab and class. The student subjects included twelve sixth grade Life Science students from my largest three classes so as to get students with a wide range of abilities. Data were collected through a variety of ways such a science survey to determine student perceptions towards science and science learning, an inquiry assessment to determine student knowledge of inquiry elements and processes, laboratory exercises to introduce students to specific scientific ideas such as diffusion, osmosis, respiration and cell membrane selectivity, a chapter test to determine whether or not content material has been learned, and a final class evaluation to determine the effectiveness of class activities and strategies. The data were analyzed to determine both specific and general emerging themes.

The five generalized emerging themes that came from the data were: students are learning from the guided inquiry process, students learn more from the inquiry process than by having someone tell them the facts, students are learning to think, students learn more by working with others, and students gain confidence and competency by doing inquiry.

Specific emerging themes from the pre- and post-science surveys appear to suggest that students do think about what they are thinking (metacognition), learn more if they have a choice about what they are learning, understand more of what they are learning if they can talk it over with a partner, learn more when they work in a group and share ideas, find that discovering

answers to their own questions is interesting, like to discuss what they have learned, learning is finding out about things that interest them, do not think they can learn more from reading than doing, and think that facts discovered on their own are more memorable than facts someone else tells them.

The specific emerging themes from the final part 1 classroom evaluation suggest that the following classroom activities showed a higher positive correlation in helping students learn: working with lab partners, hands on labs, the teacher showing examples and explaining, and the way class was taught. The specific emerging themes of part 2 of the final class evaluation which demonstrated a more positive correlation to classroom learning are: making lab observations, feeling confident they can do a lab and get results, and understanding what the data are showing them. The specific emerging theme of part 3 of the final class evaluation that shows a positive correlation to classroom learning is the following statement: students maintain they have learned how to think through a problem or question.

The analysis of the chapter test also appears to support the findings of Rivet and Krajcik (2008) that utilizing prior knowledge and the everyday life experiences of students serves as a springboard for understanding complex science concepts since students answered the questions on diffusion, osmosis, respiration and cell membrane selectivity correctly 92 % of the time. Rivat and Krajcik (2008) also maintain that contextualized instruction, which seeks to use current events or relevant situations that occur outside of the science class that are of personal interest to students, will serve to motivate and engage students in targeted science learning. Experimenting upon Gummy Bears is of great interest to sixth graders.

### Performance in Analyzing Data

It would appear from the analysis of both the laboratory exercises and the inquiry assessments that students appear to grasp the science skill of analyzing data. Data analysis in the inquiry assessments went from 9 % in the pre-inquiry to 88 % in the post-inquiry. Their performance in the laboratory exercises showed a somewhat different picture. The labs increased in difficulty as the science concept increased in complexity. The labs followed this sequence: diffusion, osmosis, respiration and cell membrane selectivity. Students were able to formulate a relevant analysis of the data 90 % of the time in the diffusion lab, 60 % of the time in the osmosis lab, 82 % of the time in the respiration lab and 87 % of the time in the cell membrane selectivity lab. There was a decrease in performance with the osmosis lab, an increase in performance with the respiration lab followed by a slight increase in performance with the cell membrane selectivity lab.

During the osmosis lab, students measured the water weight gain of their Gummy Bears when soaked in water to simulate osmosis. Measurement issues emerged during this lab because the Gummy Bears became slimy and difficult to handle and therefore difficult to weigh after being soaked in water. Students love Gummy Bears and squeezed them when handling them, which forced water out of the Gummy Bears so that they weighed less. These observations agree with the findings of Kanari and Millar (2004) and Germann and Aram (1996) that students may not be aware of the need for accuracy in recording data, observations, procedures, and results. This may explain the reason why some Gummy Bears lost weight after being soaked in water, and why student data collection appeared to be flawed in a few cases, and thus yielded erroneous results.

The difference between student performance in the inquiry assessments and the actual lab

performance may be explained by the difficulty in applying a skill one may understand in one's head to an actual real world application. This result in learning to analyze data tended to reinforce the National Research Council's (2007) statement that students may improve in their performance of science skills as they age, but this is not a uniform progress with either age or the individual. Students may have needed more opportunities according to Hanuscin and Park Rogers (2008) to practice the basic science skills of observation and inference which help in data analysis as well as conclusion synthesis. They may have also needed more discussions with other students and their teacher in order to sharpen their reasoning skills. Students did get more competent in data analysis as they got more opportunities to practice in lab so that they achieved an overall success rate of 88% on the post-inquiry assessment.

#### Performance in Conclusion Synthesis

Students appeared to have grasped the skill of conclusion synthesis according to an analysis of laboratory exercises and inquiry assessments. Student performance in learning to synthesize a relevant conclusion to an inquiry lab showed a decrease in performance after the osmosis lab followed by another decrease in performance after the respiration lab, and then an increase in performance after the membrane lab. Students appeared to have a more difficult time in learning to synthesize a conclusion, which is a summary analysis of the entire lab and the scientific concepts it seeks to demonstrate. Student performance in conclusion synthesis went from 6 % in the pre-inquiry to 88 % in the post-inquiry.

These results tend to prove the National Research Council's (2004) assertion that conceptual knowledge such a scientific theory or principle is a type of knowledge that is not likely to have been learned in everyday life experiences. It usually requires time to be spent in the inquiry

process to develop this knowledge, and students often require help in grasping these highly organized concepts (National Research Council, 2004).

The insights developed by Vellom and Anderson (1999) in their article about the relationship between experience with phenomena observed or collected during laboratory experiments and scientific theories appear to apply here. Scientists in real life are primarily engaged in a search for patterns that explain experimental or real world phenomena, and data collection serves as a means to this end. Some students may do poorly in conclusion synthesis because they have less experience and are unable to find these patterns, and so cannot link observations to scientific principles in order to interpret their results according to Vellom and Anderson (1999).

Students may also be unaware of the variety of cognitive strategies available to them, which is very important to being able to decide when, where and how to employ them in organizing and interpreting facts and data into related pieces according to the National Research Council (2007). Being aware of one's own limitation in knowledge such as knowing the difference between opinion and evidence is important in being able to reason in a scientific context within a scientific inquiry (National Research Council, 2007). Students may also struggle to formulate a conclusion according to Hanuscin and Park Rogers (2008) because they need many opportunities to practice the basic science skills of observation and inference, as well as more discussions with other students and their teacher. Students did get more competent in conclusion synthesis as they got more opportunities to practice in lab so that they achieved an overall success rate of 88% on the post-inquiry assessment.



## Discussion

While inquiry based laboratory exercises appear to improve student performance in such science process skills as data analysis and conclusion synthesis, the author has much to learn about teaching complex scientific ideas to younger children. This study has helped me see places in my practice which need to be changed in order to help my students learn more deeply and to make them become more interested in science.

My students did not have much actual experience with the inquiry process and were not familiar with such inquiry elements as the independent and dependent variables, constants, controls, data analysis and conclusion synthesis. They appeared to enjoy conducting most of the experiments, but found analyzing the data and synthesizing a conclusion to be challenging. They got “right to the point” as they saw it in their writing and reasoning. This outcome might be explained by the National Research Council (2007) findings that younger students have not had much experience and have less prior knowledge upon which they could draw for help in conducting an experiment, or analyzing data and synthesizing a conclusion. A few students also had difficulty in handling unexpected results or situations as mentioned by Kanari and Millar (2004). Some students focused on the data which proved their hypothesis and ignored contrary data, which demonstrated relation-based scientific reasoning according to Tytler and Peterson (2004). Others had trouble calculating percentages and entering data into their data tables as mentioned in the article by Amsel and Brock (1996).

A few of the students appeared to use phenomenon-based reasoning as described by Tytler and Peterson (2004). They were not able distinguish between an explanation for data occurrence and a description of the occurrence. They were looking, seeing and enjoying, but not using a

critical eye. Their performance bears out the National Research Council's (2007) assertion that young students like to experiment, but their experiments are not systemically structured and their observational and reasoning skills are less than perfect

It appeared that many of the students were not ready developmentally to engage fully in the inquiry process. Though it did seem to inspire them towards discovery since the statement of concerning facts they discovered on their own were more memorable than facts someone else told them became much more important to them during the post-science survey. They also appeared to desire to take control of their own learning since the statement I learn more if I have a choice about what I am learning also became most important to them during the post-science survey.

### Recommendations

I believe that more research needs to be done on not only how younger students learn science using the inquiry process, but how they develop the ability to utilize science process skills such as data analysis and conclusion synthesis. More research needs to be done on the mental development of younger students and their reasoning processes. Research needs to be done on selecting or formulating strategies that can succeed and develop younger minds.

This research project has greatly opened my mind and heart to the abilities and needs of younger students. I think that inquiry has great potential to further science education because students find sustained interest and engagement with this strategy. Though Life Science in my district is not currently structured towards inquiry, I will work towards structuring my classes so that my primary method of teaching content is inquiry driven.

## **APPENDIX A: IRB APPROVAL LETTER**



University of Central Florida Institutional Review Board  
Office of Research & Commercialization  
12201 Research Parkway, Suite 501  
Orlando, Florida 32826-3246  
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276  
[www.research.ucf.edu/compliance/irb.html](http://www.research.ucf.edu/compliance/irb.html)

### Notice of Expedited Initial Review and Approval

From : UCF Institutional Review Board  
FWA00000351, Exp. 10/8/11, IRB00001138

To : Melonie Moore

Date : November 25, 2008

IRB Number: SBE-08-05941

Study Title: **Can Inquiry Based Labs Improve the Performance of Science Process Skills such as Data Analysis and Conclusion Synthesis?**

Dear Researcher:

Your research protocol noted above was approved by **expedited** review by the UCF IRB Vice-chair on 11/24/2008. **The expiration date is 11/23/2009.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The category for which this study qualifies as expeditable research is as follows:

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at <http://iris.research.ucf.edu>.

**Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies.** The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 11/25/2008 11:03:56 AM EST

IRB Coordinator

## **APPENDIX B: SCIENCE SURVEY APPROVAL**

**Melonie Moore**

---

**From:** Reed, Olivia (Heinemann) [olivia.reed@heinemann.com]  
**Sent:** Friday, June 27, 2008 10:24 AM  
**To:** Melonie Moore  
**Subject:** RE: [BULK] Permission to use student survey

You have our permission to use the excerpt from *Nurturing Inquiry* as detailed below. Please let me know if you have any questions.

Best,

-----  
Olivia Reed

*Permissions, Contracts, and Copyright Assistant*

Heinemann

361 Handover Street

Portsmouth, NH 03801

Phone: (603) 431-7834, ext. 1186

Fax: (603) 431-7843

[olivia.reed@heinemann.com](mailto:olivia.reed@heinemann.com)

---

**From:** Melonie Moore [mailto:mmoore@iwol.com]  
**Sent:** Monday, June 23, 2008 9:06 AM  
**To:** Reed, Olivia (Heinemann)  
**Subject:** [BULK] Permission to use student survey  
**Importance:** Low

Dear Sir or Madame:

My name is Melonie Moore and I am writing to request permission to make and use a copy of the student survey (Chapter 2, page 10, figure 2-1) in *Nurturing Inquiry: Real Science for the Elementary Classroom* by Charles R. Pearce. I will be using these copies as part of the data for my master's thesis in science education from the University of Central Florida. I will need to make 150 photocopies of the survey and distribute them to my science students. I currently teach 6<sup>th</sup> grade science at Lakeview Middle School in Orange County Florida, and these will be used to assess pre-science class and post-science class attitudes towards science. I would also like to know if it would be possible to remove the "No Opinion" option from the survey. If not, I will use the survey as originally written. Your help is greatly appreciated as I would like to gain a better understanding of my students' attitudes towards science.

Sincerely,

## **APPENDIX C: SCIENCE SURVEY**

## 6<sup>th</sup> Grade Science Survey

**Directions:** Read each statement and circle the appropriate response.

**SA:** Strongly Agree

**A:** Agree.

**SD:** Strongly Disagree

**D:** Disagree

- |   |    |   |   |    |
|---|----|---|---|----|
| (1) Learning is boring.   | SA | A | D | SD |
| (2) I learn best by reading chapters and answering questions.                           | SA | A | D | SD |
| (3) As I learn, it is important to think about my thinking.                             | SA | A | D | SD |
| (4) I learn more if I have a choice about what I am learning.                           | SA | A | D | SD |
| (5) When I talk things over with a partner, I understand more about what I am learning. | SA | A | D | SD |
| (6) I learn more when I work in a group and share ideas.                                | SA | A | D | SD |
| (7) Discovering answers to my own questions is interesting.                             | SA | A | D | SD |
| (8) The best way to measure learning is for my teacher to give tests.                   | SA | A | D | SD |
| (9) I learn more when I work alone.   | SA | A | D | SD |
| (10) I like to discuss what I have learned.   | SA | A | D | SD |
| (11) Learning is finding out about things that interest me.                             | SA | A | D | SD |
| (12) Learning about science is only important for kids who want to become scientists.   | SA | A | D | SD |



- (13) I am a scientist. SA A D SD
- (14) I enjoy reading science nonfiction books. SA A D SD
- (15) A scientist asks questions. SA A D SD
- (16) Science textbooks are the best books to read to learn about science. SA A D SD
- (17) Scientists should answer old questions before answering new ones. SA A D SD
- (18) I can learn more by reading than by doing. SA A D SD
- (19) Facts I discover on my own are more memorable than facts someone else tells me. SA A D SD
- (20) Reading math, and social studies are all parts of science. SA A D SD
- (21) What do you think science is? (answer below or on another sheet of paper)

(22) Describe how you mostly learned science in previous years. Did you primarily read about science? Do experiments? (answer below or on another sheet of paper)

## **APPENDIX D: INQUIRY ASSESSMENT**

Name \_\_\_\_\_ Period \_\_\_\_\_ Date \_\_\_\_\_

## Inquiry Assessment

**Directions: Read the following paragraphs and answer the questions as completely as possible. Attach additional pages if necessary.**

1. Mr. Smith thinks that a special coffee from the Mule's Kick Company will improve the productivity of his workers on the firework's assembly line. He creates two groups of 50 workers, each and assigns each group the task of correctly inserting the fuse into a small firecracker. Group A is given the special coffee to drink while they work. Group B is not allowed to drink the special coffee. After one 8 hour work day, Mr. Smith counts up how many firecrackers that have had a fuse inserted correctly. He found that Group A had correctly inserted 4,213 fuses into firecrackers and Group B had inserted 2,579 fuses correctly into firecrackers. Please answer the following questions:

(a) What question is Mr. Smith trying to answer?

\_\_\_\_\_

(b) Is there a control group? If there is a control group, what is it? What function does a control group serve? If there is not a control group, what could serve as a control group?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(c) Is there an independent variable? If there is an independent variable, what is it? What function does an independent variable serve? If there is not an independent variable, what could be one?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

(d) Is there a dependant variable? If there is a dependent variable, what is it? What function does a dependent variable serve? If there is not a dependent variable, what could be one?

---

---

---

---

---

---

---

---

---

---

(e) Is there a constant or constants? If there is a constant or constants, what is it or what are they? What makes a constant a constant? What function do they serve?

---

---

---

---

---

---

---

---

---

---

(f) How should the results of this experiment be analyzed?

---

---

---

---

---

---

---

---

---

---

(g) What should be the conclusion in this experiment?

---

---

---

---

---

---

---

---

---

---

University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

(h) Can this experiment be improved? Explain why or why not.

---

---

---

---

---

---

---

---

---

---

---

---

---

---

---

---

**2.** Larry has noticed that his bathtub is beginning to be covered with a smelly, black mold. His neighbor tells him that Root Beer will get rid of that mold pronto. Larry decides to spray half the tub with Root Beer and the other half with Mountain Dew. He does this every morning for five days. At the end of the five days, he notices that the mold has gotten worse all over. Please answer the following questions:

(a) What question is Larry trying to answer?

---

(b) Is there a control group? If there is a control group, what is it? What function does a control group serve? If there is not a control group, what could serve as a control group?

---

---

---

---

---

---

---

---

---

---

---

---

---

---

---

---

(c) Is there an independent variable? If there is an independent variable, what is it? What function does an independent variable serve? If there is not an independent variable, what could be one?

---

---

University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

(d) Is there a dependant variable? If there is a dependent variable, what is it? What function does a dependent variable serve? If there is not a dependent variable, what could be one?

((e) Is there a constant or constants? If there is a constant or constants, what is it or what are they? What makes a constant a constant? What function do they serve?

(f) How should the results of this experiment be analyzed?

University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

(g) What should be the conclusion in this experiment?

(h) Can this experiment be improved? Explain why or why not.

University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

## **APPENDIX E: CLASS EVALUATION**



## Class Evaluation

### **Part 1: How much help did you receive in learning from the following class activities?**

	Was of No Help	Was of Little Help	Helped a Lot	Helped a
<b>Great Deal</b>				
1. Teacher Notes	1	2	3	4
2. Teacher Lectures	1	2	3	4
3. Reading Textbook	1	2	3	4
4. Hands-on Labs	1	2	3	4
5. Completing Lab Reports	1	2	3	4
6. Working with Lab Partners	1	2	3	4
7. Work Sheets	1	2	3	4
8. Teacher showing examples and explaining	1	2	3	4
9. Other students explaining their work	1	2	3	4
10. The way class was taught	1	2	3	4

### **Part 2: How much help has this class given you in learning the following skills?**

	Was of No Help	Was of Little Help	Helped a Lot	Helped a
<b>Great Deal</b>				
1. Writing a lab hypothesis	1	2	3	4
2. Writing a lab analysis	1	2	3	4
3. Writing a lab conclusion	1	2	3	4
4. Making lab observations	1	2	3	4
5. Making graphs/tables	1	2	3	4
6. Answering lab questions	1	2	3	4
7. Understanding what the data was showing me	1	2	3	4
8. Feeling confident I can do a lab and get results	1	2	3	4

### **Part 3: How much help has this class given you in improving in the following areas?**

	Was of No Help	Was of Little Help	Helped a Lot	Helped a
<b>Great Deal</b>				
1. Understanding main concepts in science	1	2	3	4

2. Understanding the nature of science	1	2	3	4
3. Understanding how inquiry is done	1	2	3	4
4. Understanding the parts of the inquiry process	1	2	3	4
5. Completing an inquiry process or lab	1	2	3	4
6. Ability to think through a problem or question	1	2	3	4
7. Interest in science	1	2	3	4

**Part 4: How much of what you learned in this class will you remember and use in other classes and life? Did this class make you want to continue in science and learn more about science?**

## **APPENDIX F: DIFFUSION LABORATORY EXERCISE**

## DIFFUSION

Diffusion is the movement of molecules from areas of high concentration to areas of low concentration. Cells use diffusion to reach a state of equilibrium or balance. In this lab investigation, you will be seeing diffusion at work with common household items.

**Question:** What will happen to the food coloring and the water as diffusion occurs?

**Hypothesis:** (Predict what you think will happen in this lab)

*The water will slowly change color and look like  
tiny, spreading, green streaks*

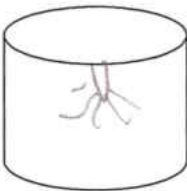

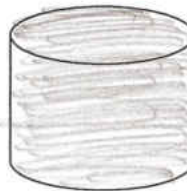
**Materials:**

Beakers      Cups      Food coloring      Water      Clock      Spoon

**Procedure:**

1. Take your beaker and fill it with 300 mL of water. Pour the water into your cup.
2. Place ONE drop of food coloring into the cup. Make sure that it does not splash; you want to drop it just at the water's surface. Record your initial observations.
3. After 10 minutes record your observations.
4. Then take a spoon and stir the mixture. Record your observations.
5. Clean up your equipment and your area.
6. Answer the Questions and formulate your Analysis and Conclusion.

**Data Table:**

	Initial observations	Observations after 10 minutes	Observations after stirring
<b>Describe what you saw happening</b>	<i>The blob hit the water and spread out</i>	<i>the water was almost solid</i>	<i>completely solid</i>
<b>Draw what you saw</b>			



University of Central Florida IRB  
 IRB NUMBER: SBE-08-05941  
 IRB APPROVAL DATE: 11/24/2008  
 IRB EXPIRATION DATE: 11/23/2009

**Questions:** (Attach additional pages if necessary.)

1. How long did it take the water to change color?

It took about 8 minutes for it to change color.

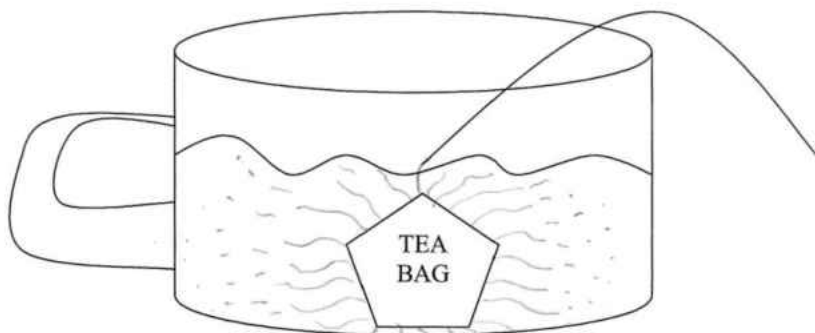
2. When did the water turn a uniform or consistent color?

The top middle (where we dropped the drop) had a uniform or consistent color.

3. You are sitting at home and you are not feeling well. Your parent tells you to make a glass of hot tea. Explain what happens when you put the tea bag into the hot water. Make sure you use the following words in your explanation: diffusion, molecules, move, high concentration, low concentration.

When you put a tea bag in hot water it has high concentration where you dropped the bag, the area far from the tea bag is known as low concentration. When the tea molecules move around in the glass and the water turns to tea its called diffusion.

4. Draw what happens to the tea when the tea bag is placed in the glass of hot water.



Name: \_\_\_\_\_ Period: \_\_\_\_\_ Date: \_\_\_\_\_

**Analysis:** Explain how the food coloring diffusing in water can be related to or is like the diffusion of molecules through the cell membrane. Explain why your hypothesis was true or false. Identify the independent variable, dependant variable, constant(s) and control if present. Attach additional pages if necessary.

Food coloring dropped into water is like the diffusion of molecules because they both release something that can spread. My hypothesis was correct because the experiment did exactly what I predicted. The independent variable was the amount of strength you used to squeeze out the food coloring making a large to small drop into the water. The dependant variable was how the water changed color. The constant was how much water we used. The control is the water without food coloring.

**Conclusion:** Explain what happens when the food coloring was added to the water. Make sure you use the following words in your explanation: diffusion, molecules, move, high concentration, low concentration. Attach additional pages if necessary.

When you drop the food coloring in water there is high concentration where you dropped the food coloring. The areas far from the drop has low concentration in the beginning and most of the rest of the time. When the food coloring molecules moves around in the glass the water eventually is the color of the food coloring. This process is called diffusion.



## **APPENDIX G: OSMOSIS LABORATORY EXERCISE**

## GUMMY BEAR OSMOSIS

Water molecules move by diffusion into and out of cells. The diffusion of water through a cell membrane is called osmosis. Remember that the movement of molecules takes place from an area of high concentration to an area of low concentration. Cells use osmosis to reach a state of equilibrium or balance with the water inside of them and the water outside of them.

**Question:** What will happen to the size of the gummy bear after soaking in each substance?

**Hypothesis:** (Predict what you think will happen in this lab)

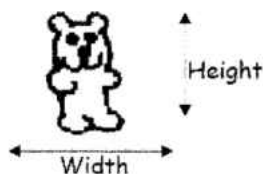
I think will happen to the gummy bear after soaking in in the water the gummy bear will absorb the water in the gummy bear to what it would weigh more.

### Materials:

Cup	Distilled Water	Gummy Bear	Ruler
Masking Tape	Wax Paper	Paper Towel	Calculator
Triple Beam Balance	Sharpie		

### Procedure:

1. Use the Sharpie to label your cup with your names and class period.
2. Use the ruler to find the height and width of your gummy bear.



3. Use a triple beam balance to find the mass of your candy bear.
  - a. Use a piece of wax paper to protect the pan of the balance.
  - b. Mass of the wax paper = 0.8g
  - c. Mass of the gummy bear and wax paper = 3g
  - d.  $C - B =$  2.2g = mass of the gummy bear
4. Record descriptive observations about the gummy bear.

The gummy bear is gross, lumpy, sticky, not soft just hard and fat.



University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009



- 
- 
- 
5. Fill your cup  $\frac{1}{2}$  way full with distilled water (not water from the sink).
  6. Put your gummy bear into the cup.
  7. Set the cup aside for one day.
  8. After the gummy bear has been in the distilled water overnight, **gently** take it out of the water and pat it dry. Be very careful because the candy is now breakable.
  9. Use the ruler to find the height and width of your gummy bear.
  10. Use a triple beam balance to find the mass of your candy bear.
    - a. Use a piece of wax paper to protect the pan of the balance.
    - b. Mass of the wax paper = \_\_\_\_\_
    - c. Mass of the gummy bear and wax paper = \_\_\_\_\_
    - d.  $C - B = \underline{2.3g}$  = mass of the gummy bear

**Data Table:** Record your measurements and observations in the data table below.

Before Soaking in Water	After soaking in Water
Height: $\frac{1}{2}$ cm	Height: $\frac{1}{2}$ cm
Width: 1 cm	Width: 1 cm
Mass: 2.2 g	Mass: 2.3 g
Observations: The gummy bear still looks like a regular gummy bear. (It's green.)	Observations: The gummy bear is a little bigger and sweeter.



Name: \_\_\_\_\_ Period: \_\_\_\_\_ Date: \_\_\_\_\_

**Calculations:** Calculate the percent change in the size of the candy. Show all work in the area below equations!

$$\% \text{ Change in Candy Height} = \frac{(\text{Height after soaking}) - (\text{Height before soaking})}{(\text{Height before soaking})} \times 100$$

Didn't change

$$\% \text{ Change in Candy Width} = \frac{(\text{Width after soaking}) - (\text{Width before soaking})}{(\text{Width before soaking})} \times 100$$

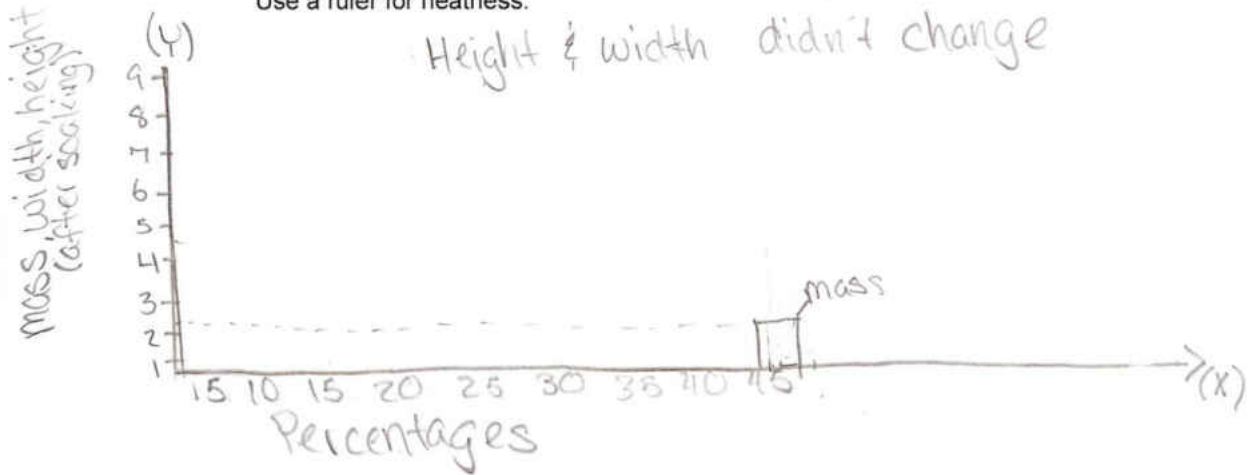
Didn't change

$$\% \text{ Change in Candy Mass} = \frac{(\text{Mass after soaking}) - (\text{Mass before soaking})}{(\text{Mass before soaking})} \times 100$$

$$2.3\text{g} - 2.2\text{g} = 0.1\text{grams}$$

4.5 gain

**Graph:** Graph the percent changes on a Bar Graph in the area below. Label the x-axis as percentages and use the y-axis to place the height, width and mass bars upon. Use a ruler for neatness.



University of Central Florida IRB  
 IRB NUMBER: SBE-08-05941  
 IRB APPROVAL DATE: 11/24/2008  
 IRB EXPIRATION DATE: 11/23/2009

**ANALYSIS:** Explain how what happened to the candy after it was soaked can be related to or is like the process of osmosis in cells. Explain why your hypothesis was true or false. Identify the independent variable, dependant variable, constant(s) and control if present. Attach other pages if necessary.

After the candy was soaked in to the water the candy gained weight. The first gummy bear that we left over night totally dissolved, then the second gummy bear only absorbed a little bit of water. The second gummy bear was just the beginning of osmosis. Based on my hypothesis it was true. My hypothesis was correct because when it was in the water the gummy bear absorbed the water and gained weight. The independent variable was the time the gummy bear was in the water. The dependent variable was the rate of osmosis. The constant was the type of bear, water, and cup. The control was the unused bears.

**CONCLUSION:** Explain the results of this lab investigation using the concept of OSMOSIS. Make sure to use the following words: osmosis, water, diffusion, high concentration, low concentration, and gummy bear measurement changes. Attach other pages if necessary.

When we put the gummy bear into the water the gummy bear was the low concentration of water but the water was the high concentration. Before osmosis/diffusion the gummy bear weighed 2.2g then after we soaked the bear he weighed 2.3g.



## **APPENDIX H: RESPIRATION LABORATORY EXERCISE**

## RESPIRATION: HOW SWEET IT IS!

Respiration occurs in the cells of all living things. During respiration, chemical reactions occur that break down food molecules into simpler substances and release their stored energy. Glucose, a type of carbohydrate, is being broken down into carbon dioxide and water in order to release stored energy during respiration that will be used by an organism to power its life processes.

**Question:** Do various sweeteners provide more or less energy to yeasts during their respiration process?

**Hypothesis:** (Predict what you think will happen during the experiment)

I think that bag w/ sugar & yeast will  
produce the most CO<sub>2</sub> gas.

### Materials:

Zippered clear plastic freezer bags	Very warm water
Rapid rise yeast	Packets of sugar
Permanent marking pens	Packets of Sweet 'n Low (saccharin)
Measuring teaspoon	Packets of Equal (aspartame)
Metric ruler	Very warm grape juice and lemon juice
Graduated cylinders	Large, graduated beaker (500 ml or better)

### General Procedure:

1. Each group will have a control in addition to testing 3 sweetened liquids:
  - a. First bag will be the control and will contain only water and yeast.
  - b. Second bag must contain sugar, water and yeast.
  - c. Third bag must have an artificial sweetener, water and yeast.
  - d. Forth bag must contain a fruit juice and yeast.
2. Each group will have 4 plastic bags that are labeled with a permanent pen. Each bag will be labeled with the lab partner's names, period, bag number and contents. Example: Johnny Smith and Jamie Jones, 3<sup>rd</sup> period, Bag # 2, Sugar, Water and Yeast.
3. **Design a Data Table on page 3 that will include the following information: the bag number and contents of each of the four bags, and the two time period of 10 minutes and 20 minutes. Each cell of the table will be used to record the volume displacement of the amount of carbon dioxide gas produced by the yeast.**
4. In the Data Table under Bag # 1 write down control.
5. In the Data Table under Bag # 2 write down "Sugar".
6. In the Data Table under Bag # 3 write down "Equal" if you use Equal or "Sweet 'n Low" if you use Sweet 'n Low.



University of Central Florida IRB  
IRB NUMBER: SBE-08-05941  
IRB APPROVAL DATE: 11/24/2008  
IRB EXPIRATION DATE: 11/23/2009

7. In the Data Table under Bag # 4 write down "Grape Juice" if you use grape juice or "Lemon Juice" if you use lemon juice.

**Detailed Procedure:**

1. **For Bag # 1:** Place 30 ml. of very warm water in the bag, then place 1 teaspoon of yeast in the bag. Press the air out of the bag then seal the bag and mix well.
2. **For Bag # 2:** Place 30 ml. of very warm water in the bag, then place 1 packet of sugar and 1 teaspoon of yeast in the bag. Press the air out of the bag then seal the bag and mix well.
3. **For Bag # 3:** Place 30 ml. of very warm water in the bag, then place either 1 packet of Sweet 'n Low or 1 packet of Equal and 1 teaspoon of yeast in the bag. Press the air out of the bag then seal the bag and mix well.
4. **For Bag # 4:** Place 30 ml. of either very warm grape juice or very warm lemon juice in the bag, then place 1 teaspoon of yeast in the bag. Press the air out of the bag then seal the bag and mix well.
5. **All bags must remain at a constant temperature so everyone must hold a bag in their hands or place it carefully under your armpit for 10 minutes to keep it warm so the yeast can "respire".**
6. After 10 minutes is up, you will determine the amount of carbon dioxide the yeasts have produced after respiration of the "sugar" or "sugar substitute" using volume displacement.
7. To do this, put your bag into a large, graduated beaker that is filled with 300 ml. of water. Record the new level of water in ml. on a piece of paper after the bag is placed into the large beaker. Subtract the new water level from the old level. This new number is the "approximate" amount in ml. of carbon dioxide that the yeast have produced during respiration. **Do this for each bag!**
8. **Record this volume in the Data Table in the 10 Minute Row for each Bag #.**
9. Now dry off the bags gently with a paper towel (make sure the seal is tight!) and repeat steps 5, 6, and 7 again by keeping the bags warm again for another 10 minutes and then measuring the volume displacement, which is the difference between the water levels before and after the bag is placed into the beaker to see if the yeast have produced more carbon dioxide.
10. **Record the new volume in the Data Table in the 20 Minute Row for each Bag #.**
11. **Clean up!**



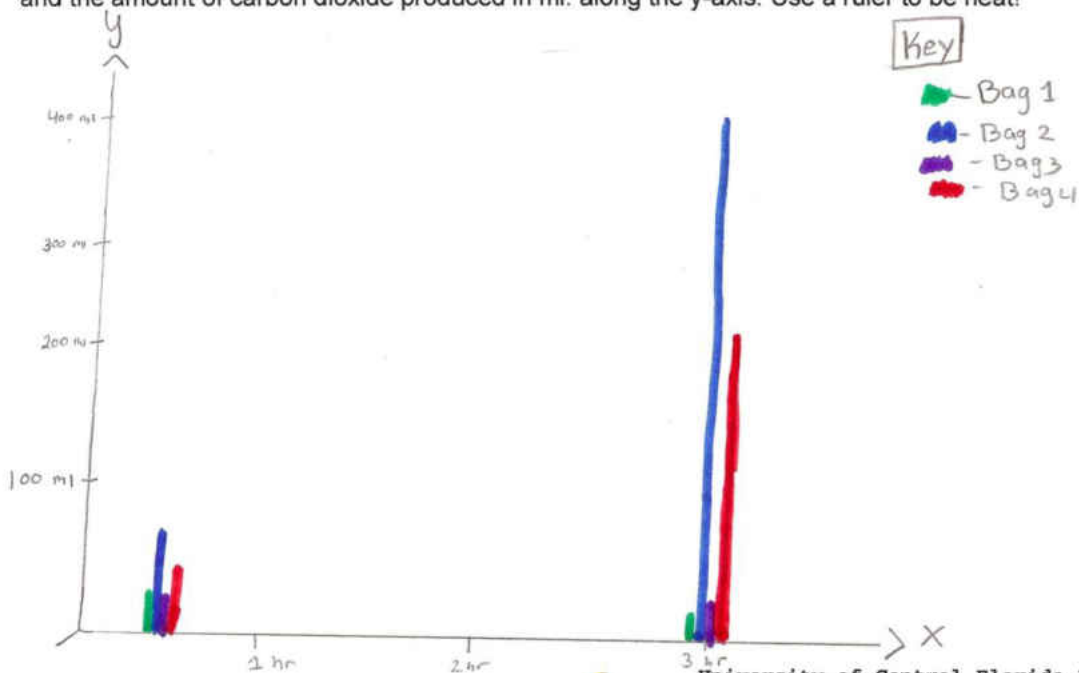
Name: \_\_\_\_\_ Period: \_\_\_\_\_ Date: \_\_\_\_\_

**Data Table**

	Vol Dis 20min		Vol Dis min	
Bag 1	10ml		10ml	
Bag 2	50ml		350-400ml	
Bag 3	Equal 10ml	sweetin low 10ml	Equal 10ml	Sweetin low 10ml
Bag 4	lemonade 10ml	Grape 30 ml	lemon 10ml	Grape 200-250 ml

**Key** Bag 1 (control) → water + Yeast  
 Bag 2 → water + yeast + sugar  
 Bag 3 → water + yeast + False sugar (Equal/Sweetin low)  
 Bag 4 → water + yeast + Juice (lemon / Grape)

**Create a bar graph** of your results below. The time (in minutes) should be on the x-axis and the amount of carbon dioxide produced in ml. along the y-axis. Use a ruler to be neat!



**QUESTIONS:**

1. Using your lab results, do you think that sugar and the fruit juice provide the same amount of energy? Explain.

No. sugar gave the yeast more energy. After 3 hrs, bag 2 (w/ sugar) had 350-400 ml. & bag 4 (w/ juice) had 10 ml. Bag 4 w/ grape juice produce 200-250 ml. CO<sub>2</sub> gas. The sugar in bag 2 produced more energy for the yeast to respire & produce CO<sub>2</sub> gas.

2. Using your lab results, do you think the sugar substitute provided the same amount of energy as sugar? Explain.

Bag 2 w/ sugar produced 350-400 ml CO<sub>2</sub> gas. Bag 3 that contained either Equal or Sweet n' low produce only 10 ml CO<sub>2</sub> gas. Since Bag 2 produced much more CO<sub>2</sub> gas than the fake sugar in b3, real sugar provides energy to the yeast which fake sugar did not.

3. Using the lab results of your group and others, do you think that each type of sugar substitute produced the same amount of energy? Explain.

Neither fake sugar gave the yeast energy because they only produced 10 ml of CO<sub>2</sub> gas.

4. Using the lab results of your group and others, do you think that each type of fruit juice produced the same amount of energy? Explain.

NO, because lemon had 10 ml & Grape had 200-250 ml. & also the reason is because lemon had no sugar so the yeast couldn't consume it but grape yeast could.





Name: \_\_\_\_\_ Period: \_\_\_\_\_ Date: \_\_\_\_\_

**ANALYSIS:** What sweetener caused the yeast to produce the most gas in your experiment? What sweetener caused the yeast to produce the second largest amount of gas in your experiment? What sweetener caused the yeast to produce the least amount of gas in your experiment? What gas did the control produce? How is respiration in yeasts like respiration in humans? Explain why your hypothesis was true or false. Identify the independent variable, dependent variable, constant(s) and control if present. Attach other pages if necessary.

The one that produced the most was b2 with the sugar, which produced 350-400ml, the second most produce gas was b4 Grape juice, which produced 200-250 ml. The bag that produce the least was b3 because they all produced 10ml & b4 lemon & Grape only had 10ml, all sweetners. The control produced CO<sub>2</sub> gas. Both breathed air CO<sub>2</sub>. True because sugar did produce the most CO<sub>2</sub> gas which was 350-400ml. Independent variable, controlled bag contents, dependent variable time yeast to respire, constant, type of yeast & bags, type of sugar & Juices Control b1.

**CONCLUSION:** Explain the results of this lab investigation using the concept of RESPIRATION. Make sure to use the following words: respiration, chemical reaction, break down, amount of stored energy in each sweetener or sugar substitute, amount of carbon dioxide produced by yeast respiring each sweetener or sugar substitute. Attach other pages if necessary.

Respiration is when the yeast broke down the amount of stored energy in the sugar to produce CO<sub>2</sub> gas. When the sweetener or sugar substitute produced CO<sub>2</sub> gas it was a chemical reaction when b2 containing sugar, yeast, water produced 350-400 ml of CO<sub>2</sub> that is the amount of Carbon dioxide produced by yeast respiring each sweetener or sugar substitute.



## **APPENDIX I: CELL MEMBRANE LABORATORY EXERCISE**

## MOLECULE MOVEMENT ACROSS AN EGG MEMBRANE

The cell membrane is the protective layer around all cells. The cell membrane regulates interactions between the cell and its environment. The cell membrane utilizes various methods such as diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis to move various substances into and out of the cell. The cell membrane will not permit certain substances to enter the cell.

**Question:** What effect will soaking in various substances have on the mass and circumference of the egg?

**Hypothesis:** (Predict what you think will happen in this lab)

I think that the egg will soak up the water and become bigger.

**Materials:**

Beaker for measurement	Egg	String
Plastic Cups	Metric Ruler	Vinegar
Water	Corn syrup	Triple Beam Balance

**Procedure:**

- Place an egg in **vinegar** for two days. Remove any shell left on the egg.
- Choose an egg. **Write your names and period number on the cup.**
- Measure the *circumference* of the egg in millimeters with the string. Record the measurement on the data table below in Day 1-Vinegar.
- Measure the *mass* of the egg in grams and record the data in Day 1-Vinegar.
- Place your egg in your cup. Cover the egg overnight in **water**.
- Remove your egg from the water on Day 2.
- Measure the *circumference* and the *mass*. Record your data in Day 2-Water.
- Place your egg in your cup. Cover the egg overnight in **corn syrup**.
- Remove your egg from the corn syrup on Day 3.
- Measure the *circumference* and the *mass*. Record your data in Day 3-Corn Syrup.
- Place your egg and cup in the trash and clean up.

Day 1 15  
16  
Day 1 99.9  
Day 2 106.1

Day 2 212.6  
Day 3 206.7  
36.3

**Data/Observations:**

**Data Table: Egg measurements over time**

Measurement	Day 1- Vinegar	Day 2 -Water	Day 3- Corn syrup
Mass	99.9 g	106 g	69.7 g
Circumference	191 mm	200 mm	147 mm



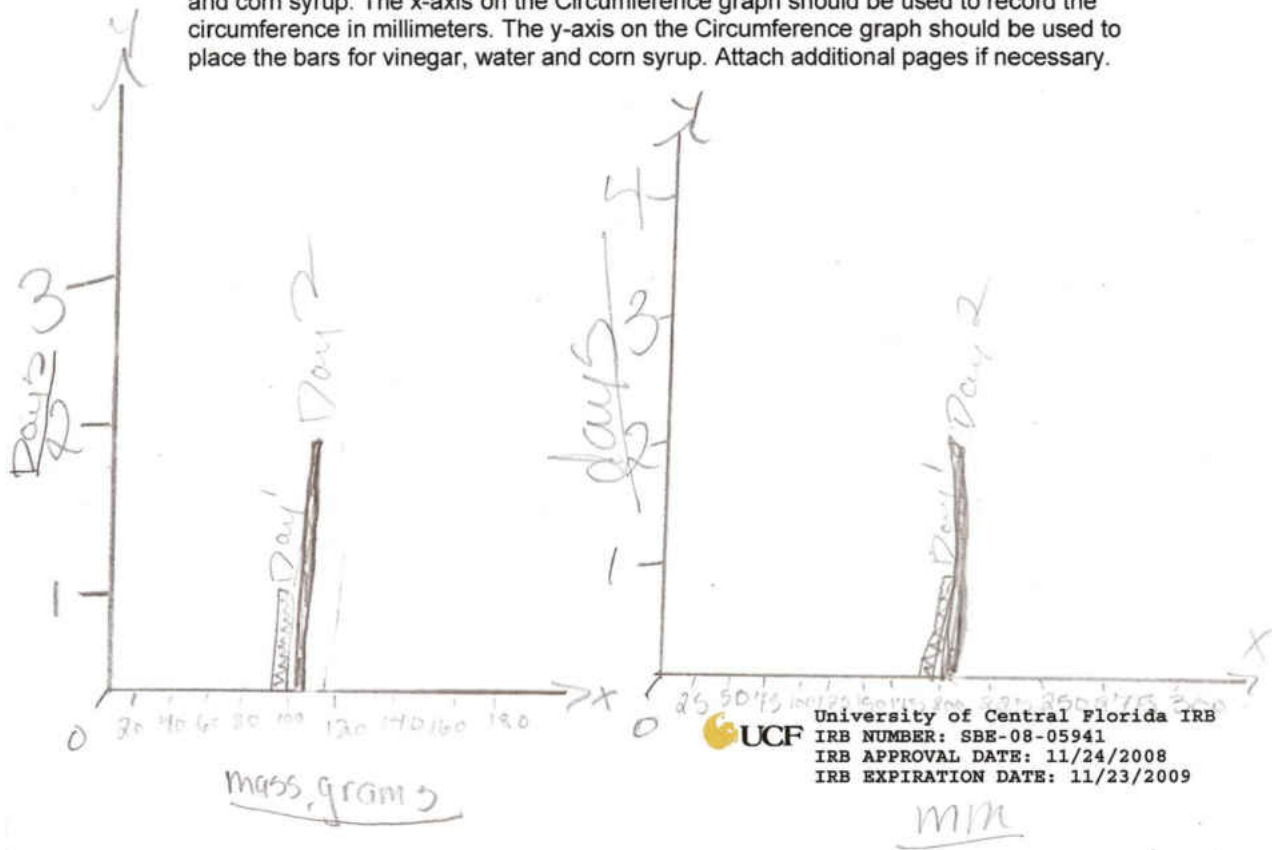
University of Central Florida IRB  
 IRB NUMBER: SBE-08-05941  
 IRB APPROVAL DATE: 11/24/2008  
 IRB EXPIRATION DATE: 11/23/2009

**Observation Notes:** (Describe any changes in the egg that you can note with your senses. Be sure to list the changes by day and substance.)

The egg doesn't have a shell anymore. It is rubbery and it smells strongly of vinegar. Before I touched it, it still looked like it had a shell.

**Graphs:**

Make two Bar Graphs below. One graph should be of the Egg's mass in vinegar, water and corn syrup. The x-axis on the Mass graph should be used to record the mass in grams. The y-axis on the Mass graph should be used to place the bars for vinegar, water and corn syrup. The other graph should be of the Egg's circumference in vinegar, water and corn syrup. The x-axis on the Circumference graph should be used to record the circumference in millimeters. The y-axis on the Circumference graph should be used to place the bars for vinegar, water and corn syrup. Attach additional pages if necessary.



University of Central Florida IRB  
 IRB NUMBER: SBE-08-05941  
 IRB APPROVAL DATE: 11/24/2008  
 IRB EXPIRATION DATE: 11/23/2009

**Questions:** (Attach additional pages if necessary.)

1. Explain the difference between what happened to the egg in water and in corn syrup.

The egg gained 60.1 grams of water and weighed 106 grams when placed in the water. The egg lost 36.3 grams of water when placed in the corn syrup and weighed 69.7 grams.

2. Calculate the mass of water that moved into and out of the egg.

60.1 grams of water moved into the egg.  
36.3 grams of water moved out of the egg.

3. Why do you think that you used an unshelled egg for this experiment?

We were trying to model a cell membrane. The egg shell is water-proof, so we had to soak it in vinegar to dissolve it, leaving only the tough egg membrane.

4. Explain what part of the egg controlled the water's movement into and out of the egg. What is the movement of water into and out of a cell called? Why does water move into and out of various areas (be sure to mention the concentrations in these areas)?

The egg's membrane, and lack of shell, allowed the water to move inside the egg. The movement of water in and out of a cell is called diffusion. Water moves around to high and low concentrations.



**Analysis:** Explain how the movement or non-movement of vinegar, water and corn syrup through the egg's membrane can be related to or is like the transport of various substances across or through the membrane of a cell. Explain why your hypothesis was true or false. Identify the independent variable, dependant variable, constant(s) and control if present. Attach additional pages if necessary.

For vinegar: The vinegar dissolved the egg shell's calcium, and left only the tough outer membrane, which is like a cell membrane.

My hypothesis is correct because the egg did soak up the water and gain weight.

Independent variable - what the egg was soaked in.

Dependent Variable - rate of diffusion/osmosis

Constants - egg, substances eggs were soaked in

Control - jar of eggs, not experimented on

**Conclusion:** Explain what happened to the egg when it stayed in the vinegar, the water and the corn syrup. Make sure you use the following words in your explanation: diffusion, osmosis, molecules, movement, high concentration, low concentration, membrane selectivity. Attach additional pages if necessary.

When the egg was soaked in the vinegar, the vinegar dissolved the egg's shell. Causing only the tough membrane to show. Then when the egg was soaked in the water the water moved from the beaker to inside the egg. Causing the egg to gain weight. When the egg was soaked in the corn syrup, the water moved out of the egg, and the corn syrup moved in. This experiment represents the process of osmosis. Diffusion is the movement of molecules from a high concentration to a low concentration. The lack of shell allowed membrane selectivity.

## **APPENDIX J: CHAPTER TEST**

## Chapter 3 Test "Cell Processes"

### Multiple Choice (6 points for each correct answer)

- D. 1. Which statement **BEST** describes how the cell membrane is like a window screen?
- A. It allows nothing in and out of the cell
  - B. It allows only water to pass into and out of the cell freely
  - C. It allows only nutrients to move into and out of the cell freely
  - D. It allows certain substances to enter the cell but not others
- D. 2. The movement of materials through the cell membrane when energy is required is called:
- A. osmosis.
  - B. diffusion.
  - C. active transport.
  - D. passive transport.
- C. 3. The raw materials needed by photosynthesis are:
- A. sugar and water.
  - B. sugar and oxygen.
  - C. carbon dioxide and water.
  - D. carbon dioxide and oxygen.
- A. 4. Which statement about photosynthesis and respiration is true?
- A. photosynthesis produces the products needed for respiration
  - B. respiration stores energy and photosynthesis releases energy
  - C. photosynthesis and respiration are the same process
  - D. photosynthesis and respiration do not have anything to do with energy
- A. 5. What does the Sun provide that living things need?
- A. energy
  - B. food
  - C. water
  - D. carbon dioxide
- A. 6. The products of cellular respiration are:
- A. energy, carbon dioxide, and water.
  - B. sugars, starches, and alcohol.
  - C. glucose, oxygen, and water.
  - D. alcohol, lactic acid, and energy.
- D. 7. The movement of substances through a cell membrane **without** the use of cellular energy is called \_\_\_\_\_?
- A. diffusion
  - B. active transport
  - C. osmosis
  - D. passive transport





- B 8. The process that **requires** cellular energy and uses transport proteins to bind with particles and move them through a cell membrane is called \_\_\_\_\_?
- diffusion
  - active transport
  - osmosis
  - passive transport

**Fill In The Blank (6 points for each correct answer)**

9. A process, which occurs in cells that **lack oxygen or one-celled organisms**, that releases small amounts of energy from glucose molecules and produces wastes such as alcohol, carbon dioxide and lactic acid is called Fermentation.
10. The process by which producers and consumers **release stored energy** from food molecules is called Respiration.
11. A process used by plants and many other producers **use light energy to produce simple sugars from carbon dioxide and water** that results in the release of oxygen is called Photosynthesis.
12. The random movement of molecules from an area where there is more of them to an area where there is fewer of them is called diffusion.
13. equilibrium occurs when molecules of one substance are spread evenly throughout another substance in equal numbers in each substance.
14. A type of passive transport that occurs when water diffuses or moves through a cell membrane is called osmosis.
15. The total of all chemical reactions in an organism is called metabolism.

**Short Answer (5 points for each correct answer)**

16. Compare and contrast respiration and fermentation.

*Respiration and fermentation are alike because they both let off energy. Respiration and fermentation are different because respiration has lots of oxygen and fermentation has lack of oxygen.*

17. Explain how photosynthesis, respiration and fermentation are related?

*Photosynthesis, respiration and fermentation are alike because they all give off energy. But photosynthesis takes in carbon dioxide and lets off oxygen and respiration takes in oxygen and lets off carbon dioxide.*

## LIST OF REFERENCES

- Amsel, E., & Brock, S. (1996). The development of evidence evaluation skills. *Cognitive Development*, 11, 523-550.
- Bell, P. & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education*, 22(8), 797-817.
- Carey, S. and Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, 28(3), 235-251.
- Chiappetta, E. L. & Koballa, T. R. (2006). *Science instruction in the middle and secondary schools* (6<sup>th</sup> ed.). Upper River Saddle, NJ: Pearson Merrill Prentice Hall.
- Christmann, E. P., & Badgett, J. L. (2009). *Interpreting assessment data*. Arlington, VA: NSTA Press.
- Crawford, B. A. (2006). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science*, 44(4), 613-642.
- Cunningham, B. M. (2008). Using action research to improve learning and the classroom environment. *Issues in Accounting Education*, 23(1), 1-30.
- Duschl, R. A., Shouse, A. W., & Schweingruber, H.A. (2007). What research says about K-8 science learning and teaching. *Principal*, 87(2), 16-22.
- Fraenkel, J. R., & Wallen, N. E. (2006). *How to design and evaluate research in education* (6<sup>th</sup> ed.). New York: McGraw-Hill.
- Germann, P. J., & Aram, R. J. (1996). Student performances on the science processes of recording data, analyzing data, drawing conclusions, and providing evidence. *Journal of Research in Science Teaching*, 33(7), 773-798.
- Hanuscin, D. L., & Park Rogers, M. A. (2008). Learning to observe and infer. *Science and Children*, 37(6), 56-57.
- Harmer, A. J., & Cates, W. M. (2007). Designing for learner engagement in middle school science. *Computers in School*, 24(1), 105-124.
- Hellden, G. F., & Solomon, J. (2004). The persistence of personal and social themes in context: long- and short-term studies of students' scientific ideas. *Science Education*, 88(6), 885-900.
- Kanari, Z., & Millar, R. (2004). Reasoning from the data: How students collect and interpret data in science investigations. *Journal of Research in Science Teaching*, 41(7), 748-769.

- Llewellyn, D. (2007). *Inquire within* (2<sup>nd</sup> ed.). Thousand Oaks, CA: Corwin Press.
- McNeill, K. L., & Krajcil, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching*, 45(1), 53-78.
- Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, set, science!* Washington, D.C.: National Academy Press.
- National Research Council (1996). *National science education standards*. Washington, D.C.: National Academy Press.
- National Research Council (2000). *Inquiry and the national science education standards: a guide for teaching and learning*. Washington, D.C.: National Academy Press.
- National Research Council (2002). *Scientific research in education*. Washington, D.C.: National Academy Press.
- National Research Council (2005). *How students learn science in the classroom*. Washington, D.C.: National Academy Press.
- National Research Council (2007). *Taking science to school*. Washington, D.C.: National Academy Press.
- Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching*, 46(2), 147-165.
- Pearce, C. R. (1999). *Nurturing inquiry: Real science for the elementary classroom*. Portsmouth, NH: (Heinemann) Reed.
- Rivat, A. E., & Krajcik, J. S. (2007). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding in middle school science. *Journal of Research in Science Teaching*, 45(1), 79-100.
- Robertson, B. (2006/2007). Getting past "inquiry versus content". *Educational Leadership*, 64(4), 67-70.
- Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, 23(1), 23-55.
- Tytler, R., & Peterson, S. (2004). From "try it and see" to strategic exploration: Characterizing young children's scientific reasoning. *Journal of Research in Science Teaching*, 41(1), 94-118.

- Vellom, R. P., & Anderson, C. W. (1999). Reasoning about data in middle school science. *Journal of Research in Science Teaching*, 36(2), 179-199.
- Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review*, 27(2), 172-223.
- Zion, M., Michalsky, T., & Mevarech, Z. R. (2005). The effects of metacognitive instruction embedded within an asynchronous learning network on scientific inquiry skills. *International Journal of Science Education*, 27(8), 957-983.