EMPHASIZING THE PROCESS OF THE SCIENTIFIC METHOD IN THE PHYSICAL SCIENCE CLASSROOM THROUGH ALTERED TECHNIQUES AND PROCEDURES

By

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ABSTRACT

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High school science requires students to use the scientific method when solving problems. The ability to solve problems in this way is a valuable and necessary skill for the classroom and life experiences. The goal of this study was to fully incorporate scientific thinking and methodology into the current curriculum. The hypothesis for this study was: a gradual release of responsibility from instructor to student will show an improvement in the ability of students to solve critical thinking problems, an integral part of the scientific method.

This project was implemented over the period of one semester, 18 weeks and covered eight units of study. The research reported here focused on three particular units: Motion, Heat Energy, and Wave Energy.

Students in a Physical Science class participated in making observations, identifying patterns, and asking questions based on the observed patterns, which led to student developed hypotheses and protocols, including data collection and analysis. Students participated in their own scientific practices, which, in turn, led to a sense of ownership and also a more thorough understanding of the scientific method and its practices as measured by lab activity accuracy and improvement in formative scores. Pre-test and post-test results indicated an improvement in students' ability to use scientific methodology.

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Many people played important roles in helping to complete this project. I would not have been able to successfully complete this endeavor without the advice, criticism and patience of others. I send special thanks to my instructor and mentor, Merle Heidemann, who patiently heard my concerns and ideas throughout the years and was always open to hearing me out on even the most trivial undertaking. You are a benefit to the College of Natural Science and an inspiration for future science teachers. Thanks also goes to Margaret Iding for all the information she has provided along with her wonderful smile.

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INTRODUCTION

Observation and Rationale

There is a problem in today's science classroom: how do we as teachers implement the practice of science so that students can use their own knowledge and skills to solve problems in and out of school? Students understand that when given a simple task, it is easy to follow written instructions. But when science students are given the opportunity to develop their own methods to solve problems, they lack the required skills. Instead of resorting to having a costly outside source solve common problems, students need to attempt addressing these themselves, even at the expense of failure. Science is the study of the natural world and why things occur the way that they do. Asking questions, sorting out thoughts, and devising logical explanations have become customary in today's complex world. However, it is given that students have had difficulty problem solving in and out of the classroom for years. For example, in my classroom students have a hard time understanding the proposal of generating their own plan for a possible solution to a problem. They are not used to developing their own ideas into working models and helping them requires a lot of patience and modeling. Even the wording of a question with its prefixes, unique science terminology, and underlying meaning may need some sort of dissection to allow the reader to comprehend the question being asked. Additionally, several of the current science assessments, both national and state, place an emphasis on these practices.

The Challenge

The single largest science content area tested on the 2013 Michigan Merit Exam

(MME) was Scientific Inquiry and Reflection section (State Summary Report, 2013), consisting of 25 of the 55 points possible. The MME is the standardized test given to all Michigan Public School students in the eleventh grade as a measure of their educational success. The state average on the science portion of the MME was only 26% of students demonstrating proficiency in science (MME Proficiency Data State Snapshot, 2013). Greenville, Michigan, where the study reported here was conducted, had 31% proficient on the MME, 35% partially proficient, while 34% were not proficient in the science portion. In summary, only one-third of our students are meeting state expectations as measured by this instrument.

These findings emphasize the need to focus on Scientific Inquiry and Reflection in instruction. The State of Michigan test developers realize this too. Those twenty five questions administered on the MME in the Scientific Inquiry and Reflection section compare to a typical allotment of only two questions for the other fifteen tested content areas in science. This indicates an emphasis on Inquiry and Reflection; for knowledge acquisition is needed in today's public education system, for soon to be independent adults.

In evaluating the usefulness of science teaching and instruction, a review of ACT data shows that students who take science classes are generally more prepared to take the ACT and, in turn, more ready for higher education than those who do not take extra science classes. Nationally, 47% of students who take three years of science, specifically Biology, Physics, and Chemistry, meet the ACT College Readiness Benchmark for performance in science. Taking at least three years of science is mandated by the Michigan Department of Education for high school graduation.

Nationwide, students who reported no science taken met the performance benchmark at a rate of only 3% (ACT Research and Policy Brief, 2013). Further, the science standards tested on the ACT are based on standards of Interpretation of Data, Scientific Investigation, and Evaluation of Models, Inferences, and Experimental Results (College and Career Readiness standards, 2014), resembling the areas that are also addressed in the MME.

Additional score reports provide clear evidence that our students are not proficient in these areas. In fact, ACT composite scores show that fewer than 26% of Michigan students meet the readiness benchmark in Biology. Equally alarming, only 31% of the 2012 National High School graduating class met the benchmark (ACT Profile Report-Michigan Graduating Class, 2012). It is apparent that a need exists to address not only that students are taught the aforementioned skills but perhaps a greater significance should be placed on how they are taught the skills.

In Michigan, and nearly every other state in the nation, the Next Generation Science Standards (2013) are being adopted as guidelines for science education. The primary focus of those standards is Scientific Inquiry. *" By the end of the 12th grade, students should have gained sufficient knowledge of the practices, crosscutting concepts, and core ideas of science and engineering to engage in public discussions on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives*" (National Research Council, 2012). According to NGSS (2013), we are a country at risk of falling behind in global economics as well in our educational preparedness. Students of today need the science skills to compete in the expanding employment opportunities that are in science-related fields. All students need a k-12 science education that prepares them for college and careers. The two documents that preceded the NGSS were the Benchmarks for Science Literacy and the National Science Education Standards, both of which are around 15 years old. Both were quality documents that states used to guide State Standards. Major advances have been made in science education. More importantly, the most effective ways those students learn science has also been changing. Critical thinking and communication skills play a pivotal role in postsecondary success, which are also the practices that scientists and engineers use on a daily basis. We use the term “practices” to indicate the active process of using gained knowledge with the skills to follow through with actions.

As stated by NGSS (2013), the standards can be broken down into three developed stages: Core ideas, Scientific Practices and Cross-Cutting Ideas. A little about each follows.

Core idea– to be considered a core idea of the NGSS standards, the following criteria must be met: The idea must have broad importance across multiple science or engineering disciplines. It must be pertinent to the understanding or investigation of more complex ideas and solving problems. It should relate to the interests and life experiences of students and must be teachable and learnable over multiple age levels with increasing levels of depth and sophistication.

Scientific Practices – These are the behaviors that scientists and students engage in as they investigate, build models and construct theories of the natural world. The National Research Council uses the term practices instead of skill because of the required use of knowledge while also applying the physical skill of doing. Practice helps avoid the interpretation of skill as rote mastery of an activity or procedure. Practice involves not only the physical ability but also the cognitive and social aspects of the process as well.

Crosscutting Concepts – These are bridges across scientific disciplines. They help provide students with an organizational framework for connecting knowledge from the various individual disciplines into a coherent and scientifically based view of the world.

Inquiry and Scientific Practices

"If a single word had to be chosen to describe the goals of science educators during the 30-year period that began in the late 1950's, it would have to be "INQUIRY" (DeBoer, 1991).

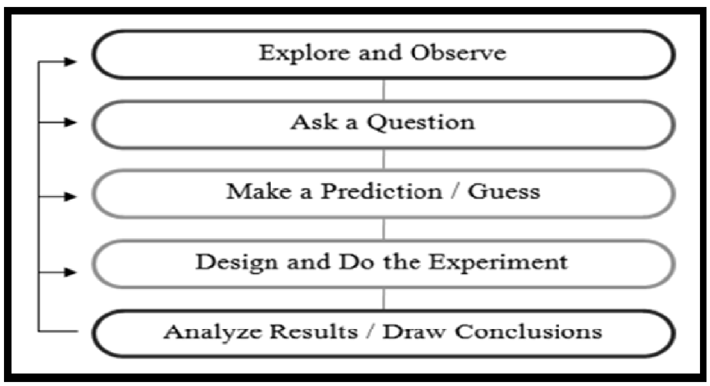
Inquiry has been defined in different ways. For example, Bell, Smetana, and Binns (2005) state: "At its heart, inquiry is an active learning process in which students answer research questions through data analysis." In another definition, "Scientific Inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996).

A recent study (Cobern, Schuster and Adams, 2014) noted, "By inquiry based teaching of science we mean instruction reflecting the investigative approach, empirical techniques, and reliance on evidence that scientists use in discovering and constructing new knowledge." Jeanpierre (1996), in the National Science Education Standards, said that "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world." In a Brief History on Inquiry: From Dewey to Standards (2006), Barrows suggested that there is a lack of agreement on the meaning of inquiry in the field of science education, broadly defining it as the use of knowledge and skills to answer questions that may exist. At times many steps may be needed to solve a problem, and other times the problem may seem simple with few steps required to solve it. Research may be involved if the problem eludes the observer. Knowing how to tackle resources should be an integral part of inquiry. However, looking at how "inquiry" has changed involves looking at current definitions and some past perspectives.

Historically, the inquiry method used in high school science classes has changed. As far back as the 1930's and 40's, students needed practice in developing a methodology for conceptualizing science. In that time period, articles spoke of developing "the habit of scientific thinking" (Quigley, et.al, 2011). By the 1950's the terminology of the process had again changed, but the thinking and practical application of science in education remained basically the same.

Twenty years ago, a shift in thinking appeared and high school science involved a fairly linear process commonly called the "scientific practices". As recently as 10 years ago, NASA promoted this linear process of thinking in what it depicts even today as the scientific method (Dunbar, 2008). Figure 1 depicts the linear nature of this thinking which is currently common in K-12 education and literature (Boynton, 2003). While contemplating Figure 1, I recalled that I, too, was using a textbook that was at least 10 years old. It too depicted the scientific model as a straight line in which steps played a predominant role.

Figure 1 Boynton's Linear Progression of Scientific Method



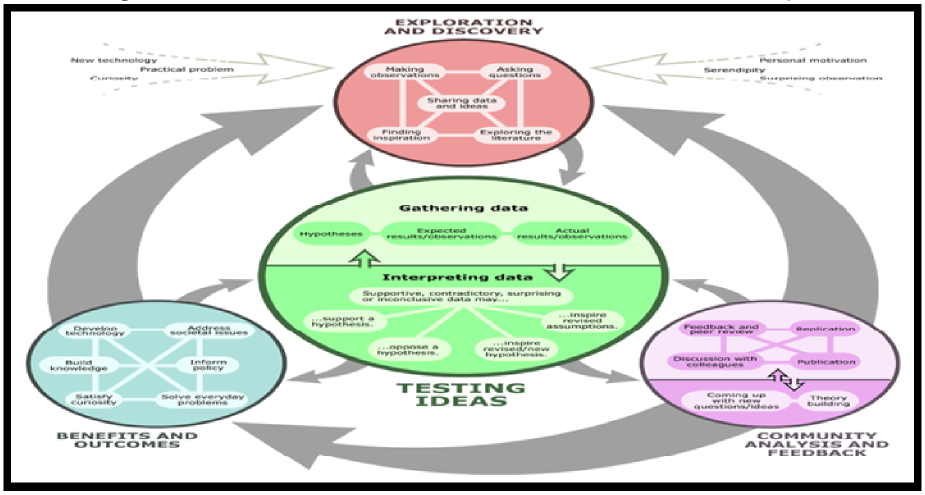
The Scientific Method, as modeled in Figure 1, was at one time thought to represent the process of science. Textbooks had diagrams and descriptions that looked similar to the one above and had little room for divergent ideas; they were rigid in their procedure. The beginning steps were followed in an order that was not to be displaced. "It was a simple recipe for performing scientific investigations" (How Science Works, http://undsci.berkeley.edu/article/howscienceworks_01, 2012). We now know that this version of the scientific method is much too rigid and simplified; it does not promote return to earlier parts or steps in the sequence and misrepresents the iterative nature of science. We have begun to understand that such a linear method is not true science with a distinct path to follow. Often presented in textbooks as a step-by-step process following a very organized and systematic path with which to follow, this figure falsely indicates an unidirectional process.

For true science to take place, as an iterative process, steps that may have once been visited may need returning to. Multiple directions can be taken, and various paths are determined by the participants' thoughts and experiences.

However, the linear scientific process model is a very systematic approach to the design. For the early years in school, this design may be useful by avoiding distracting alternate paths that could lead to confusion and miscommunication. In discussing the process of science as a summary in textbooks and articles, the linear method may be useful, but for practicing science, it is inadequate.

For an even better understanding of the true nature of science to take place, a more intricate model is needed. History has shown us that the linear model does not provide adequate movement within its parameters. According to (How Science Works: The Flowchart Graphic in http://undsci.berkeley.edu/flowchart_noninteractive.php) the working model of science, Figure 2, is deemed the opposite of the "cookbook" model. It enables a non-linear approach to science that allows for iteration within the model.

Figure 2 How Science Works: The Flowchart Graphic



Based on the model of Understanding Science and How Science Works, a few recommendations were listed for “true” science to take place.

- many different activities in many different sequences
- science depends on the interactions within the scientific community, different people at different times.
- science relies on creativity and an unpredictable course.
- scientific conclusions are revisable, asking new questions as old ones are being answered.

The process of science is iterative. It circles back on itself but can lead to deeper and deeper questioning. There are double ended arrows in the diagram indicating that one may return to earlier steps. There are many routes in the process. Scientific testing is at the heart of the process. The scientific community helps to ensure science’s accuracy. The process of science is intertwined with society. Science is a process, but one that relies on accumulated knowledge to move forward. Observations yield data which could be both quantitative and qualitative. Testing the hypotheses and theories is at the core of the science process. Ideas are supported when actual observations match expected observations and are contradicted when they do not match. The belief remains that if students practice and master the distinct skills of observing, describing, inferring, measuring and developing a hypothesis, then they, in turn, would be naturally able to solve real world problems when they were faced with them.

The aforementioned models have aspects of them which are beneficial in some sense to various learning types and situations. The Van Andel Institute has arrived at its own conceptual model of the Scientific Model (Figure 3 VAEI, Van Andel Education Institute. "QPOE Inquiry Model" Grand Rapids, MI: VAEI, 2013.—. "QPOE_2." Grand Rapids, MI: VAEI, 2013).

Greenville Public Schools decided to participate in a plan with Van Andel Institute which offers a mentoring program for teachers, which fosters inquiry based science in classrooms. Greenville science faculty has met with these partners on every professional development day, which means that we meet around 8-10 times a year. We have been developing plans, with their assistance, to become more adept in the use of their pedagogical model for scientific practices. It is a hybrid to the Understanding Science model and has many similarities. The layout of the Van Andel Model which we have used in the classroom for the past two years is shown in Figure 3 (QPOE Inquiry Model, 2013).

Figure 3 Van Andel Institute $QPOE_2$ Inquiry Model

One will notice that similar to the Understanding Science model (Figure 2), all major movement is through double ended arrows. This allows for lateral as well as vertical movement within the organizer. The Van Andel Institute model has 5 major rectangles: Question, Prediction, Observation, Explanation and Evaluation. These may seem quite similar to the linear steps of the Boynton model (Figure 1). The subunits in the green font are the skills and hands-on application that are needed to successfully move to the next major rectangle. No one order to the system must be used and returning to prior steps is possible. This allows for the student to explore different ideas and not have to return to the very beginning each time. As a poster/visual aid in my classroom, I have commonly pointed to the pertinent step when the occasion arises. I have had a fair amount of success with this model as I have become more comfortable with its use. The lab format and handout generally does not vary much from lab to lab.

That is the model used in this thesis.

Reformed Teaching

According to the text, *Assessing Hands on Science* (Brown and Shavelson, 1996), we are amidst a reform that is taking place in our science teaching. Table 1 shows the differences between pre and current reforms in science teaching since 1996. All those ideas are now almost twenty years old and these practices are more common in the classroom than previously. This change is based on the concept of how learning occurs. Students integrate new knowledge with previously obtained information and construct knowledge for themselves. In the classroom, rote memorization has given way to direct experience with scientific applications – hands on activities- that promote construction of knowledge. “Students do science, not just learn about it.” (Brown and Shavelson, 1996) Prior to this period, reform science was primarily text driven, meaning that students were presented with facts and principles and asked to read about them without ever becoming “active” in their own learning. Instructors were in charge of the labs or demonstrations; rarely would students actively get their hands dirty. Now students learn by doing; they put their hands on the materials themselves and are allowed to make mistakes and learn through exposure.

Table 1 Characteristics of Science Curriculum

Pre-Reform (Pre 1996)	Reform (After 1996-Present)
Emphasis on knowing	Emphasis on doing as well as knowing
Students’ primary learning tools are the textbook and the notepad	Students’ primary learning tools are lab notebooks and manipulatives
Broad coverage of many topics	In-depth coverage of a few topics

Table 1 (cont'd)

Students work individually	Students work individually or with partners
Spectator-based format	Activity-based format

These very strategies are used in the classroom where the work described here took place. The number of characteristics shown in Table 1 that one may implement is dependent on the exercise used in class. The complexity of the reform era has placed higher demands on instructors as well as the student. In pre-reform teaching, students worked independently and generally did not work in teams. Now students are constantly working with others and sharing ideas one with another. Lab materials as well as textbooks play an equally important role in the learning classroom. Hands-on has come forefront and is not limited to just the instructor showing examples or modeling of scientific behaviors or experimentation. "I do it, We do it, and You do it" is the phrase that defines the changes that have taken place in the classroom in the past two decades. The expectations for the student as well as the instructor have increased with time.

Today, the instructor serves more as the facilitator than just the distributor of information. He or she serves as the guide in the active participation of all students in developing the skills and knowledge to solve not only classroom skills and problems but also in the process obtaining the pertinent information to be productive in the world outside of the classroom.

One does not have to write his/her own teaching materials to be the author of classroom curriculum based on reformed teaching. The teacher is the author when selecting the appropriate activities, reading passages and videos, writing tasks, etc. and blend them into a coherent instructional unit (Blakeslee, T.,Kahan, J.(1996).

Teachers and staff may choose to implement their curriculum in different ways. While some teachers and schools are striking out on their own to interpret and implement the mix of current standards, others are joining forces and working with partners of education such as Van Andel Education Institute in Grand Rapids, Michigan. As previously described, the Van Andel Education Institute offers educational programs for teachers as well as for students. The Science Academy is founded on the idea of advancing and promoting science education and increasing the number of students who choose to pursue careers in science or related fields.

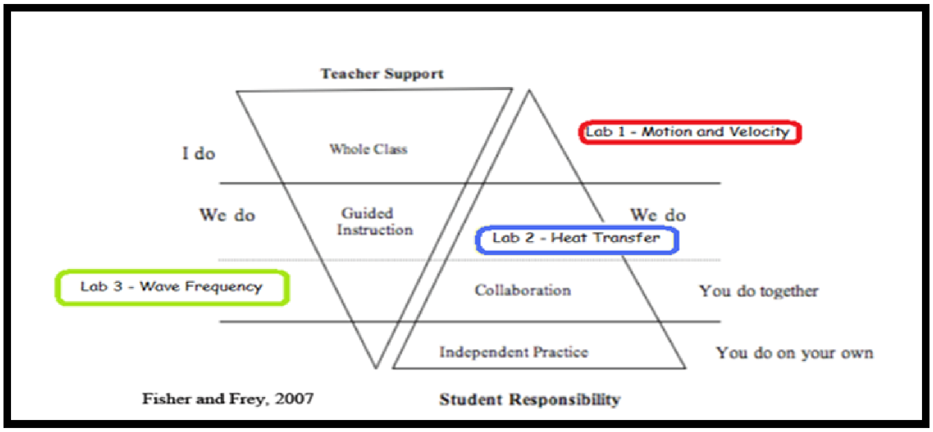
Greenville Public schools is taking on this role and is one of several school districts that is using its professional development time to work with teachers and curriculum design professionals that have classroom experience and are rehearsed in developing a inquiry-based curriculum.

Clearly, it is important to recognize that inquiry and reflection are vital concepts to teach in public education. However, of underlying importance are the pedagogical approaches and the learning abilities of the students to whom these concepts are being taught. There are several means by which students can learn how to problem solve, but research indicates that there is a need to provide a template for how teachers will effectively teach these practical skills to the students. According to Simplifying Inquiry Instruction (Bell,R., Smetana, L., and Binns, I., (2005) noted “It is important to realize that not all inquiry activities are created equal.” Others have used cookbook labs and varied their format by eliminating step by step procedures and allowing students to generate their own methods for problem solving. This allows for a more tiered approach to the inquiry levels and obtains a higher level of critical thinking. This also allows for student to access the inquiry model from different backgrounds and perspectives.

What works for one student or classroom might not work in another setting/another time period. With the goal for each student being a working knowledge of scientific inquiry, then the practical as well as the theoretical is expedient. As Anderson in Reforming Science Teaching: What Research says about Inquiry (2002)" states "… one should not address them (principles of inquiry) in isolation." Collaboration with peers and colleagues assist in developing the activities and effort needed to reach this goal. As noted by the author as well as Susan Musante in A Dynamic Alternative to the Scientific Method (2013), the science flow chart helps explain how science is done. It also generates interest and inquiry to a higher level with students recognizing that science happens in many different ways while also interacting with their different needs and backgrounds.

Figure 4 shows an effective mechanism to teaching problem solving, the G*radual Release of Responsibility* Model of instruction developed by Douglas Fisher (2006). This model indicates a progression from teacher modeling to student doing over time. Gradual release allows for a slow and very method based direction of education for students. This approach fosters greater retention and recovery of information for the student learner. This model can also be used in the progression of inquiry labs. Starting with a guided lab, students can learn their role and potentially prepare for the next tier or type of lab called guided inquiry. When they have finally mastered this concept then they can move to an open-inquiry lab in which they play the predominant role in facilitating their own learning. The three labs in which this occurred in the work reported here are included in Figure 4.

Figure 4 Gradual Release of Responsibility



For these reasons, this research focused on the processes and application of the scientific method. There existed a need to provide learners with a strong understanding of scientific practice or "methods" and the tools to conduct themselves as scientists in science classroom as well as in their worlds at large. Additionally, it is clearly a requirement for students to demonstrate the ability to conduct these practices in order to receive a diploma. The student should also achieve greater results and rewards for improved performance on high stakes assessments that are commonly used to determine college readiness and admittance.

As can be seen in Table 2, the role of the teacher was significant in the early stages of the developmental process of gradual release. In the first stage, "I do it", direct instruction from instructor was necessary to provide adequate modeling for student development. The students' role is to predominantly be a listener while asking questions and clarifying with the instructor over unknown processes. The classroom is organized and very teacher centered.

Table 2   Levels of Learning Responsibilities

Mentoring Roles & Responsibilities		
	Teacher	Student
I do it *Direct Instruction*	• Provides direct instruction • Establishes goals and purpose • Models • Think aloud	• Actively listens • Takes Notes • Asks for clarification
We do it *Guided instruction*	• Interactive instruction • Works with students • Checks, prompts, clues • Provides additional modeling • Meets with needs-based groups	• Asks and responds to questions • Works with teacher and classmates • Completes process alongside others
You do it independently *Independent Practice*	• Provides feedback • Evaluates • Determines the level of understanding	• Works alone • Relies on notes, activities, classroom learning to complete assignment • Takes full responsibility for outcome
You do it together *Collaborative Learning*	• Moves among groups • Clarifies confusion • Provides support	• Works with classmates, shares outcomes • Collaborative on authentic task • Consolidates learning • Completes process in small group • Looks to peers for clarification

As one transitions to the “We do it” or guided instruction, the student takes a more independent role. Instruction is interactive and the teacher works alongside the students. Modeling occurs but increased release is offered and the student now takes a more active role in developing their own ideas, while still working along classmates and instructor.

The next level of release is termed “You do it independently” or otherwise known as independent practice. Previous stages have prepared the student for a more independent process. The instructor provides feedback but only facilitates. At this point the student should be knowledgeable of the independent expectations and work alone.

Lastly, “You do it together” is also known as the collaborative learning model. Teacher role is to simply move among groups, and clarify questions by making the students think on their own two feet. Each student uses their peers for clarification of content and the instructor more or less observes the interactions of the students. At this point, students have now acquired the role of the instructor and devise and answer questions from within the group itself. This is where real learning takes place. When students have the ability to teach their own then we know that they are confident in their own understanding.

This chart includes a fourth level of responsibility. In each of the 3 labs that were completed, more than one level of instruction may overlap another. Although the instructor's intent might have been specific, learning and responsibilities occurred concurrently as evidenced by students' responses. Indeed, it has been this instructor's desire that students will use these principles and practices in real life experiences.

Prediction

If students receive instruction on scientific practices and conduct systematic investigations in a physical science classroom over the course of 18 weeks, their ability to solve problems, as measured by their performance on pre and post test instruments, will indicate an improvement of the students' ability to use these practices.

The subjects (students) that are involved with this research were taught the entire regular physical science curriculum that is currently required by the Michigan Framework. Additionally, the students were assessed using both formative and summative instruments in six key areas of the "scientific method" that is currently part of the curriculum taught in my classroom.

A mechanism of gradually releasing responsibility to the students will be used to emphasize the process and is described in Implementation. This approach was chosen as it aligned well with the needs of both the district and also the standards that are accepted in the discipline of Physical Science at the Secondary Level.

Demographics/Research Setting

Greenville Public Schools is located to the north of Grand Rapids and to the west of Lansing. It is in the heart of the Lower Peninsula and is considered to be part of western Michigan. According to the United States Census Bureau of 2012, Greenville has a base population of around 8500 people within the city limits and many more surrounding that go to school in Greenville. The median income per household is $28,008 with 30.1 % of citizens being below the poverty level, when compared to the state of Michigan as a whole of 16.3 %. Change has taken place in the last 10 years with the closure of a main employer known as Electrolux. Electrolux was a refrigerator manufacturing facility that employed approximately 2700 people. This turn of events has placed a strain on the employment opportunities for all citizens of Greenville whether directly or through far reaching spin offs. The current education level of residents aged 25 and older in the Greenville area is the following: 85.6 % have at least graduated from high school, while 18.9% have a Bachelor's degree or higher.

The Greenville Public Schools District has four public elementary schools, one middle school and a high school. In the 2013-2014 school year there were approximately 1,185 students enrolled at Greenville High School. The ethnic makeup of the school was 92% white, 4% Hispanic, and 1 % Black. The graduation rate was around 90% with a 6% dropout rate. Of those that attended Greenville High School, 43% received either free or reduced lunches. The maximum class size for a Greenville science section is a group of 28 students. This is mandated for safety and by union standards.

IMPLEMENTATION

Over the course of an 18 week period during the 2013-2014 school year, students were enrolled in a class titled *Introduction to Chemistry and Physics*. This course was informally referred to as Physical Science. This class was a freshmen level course and was considered a prelude to the full 36 week courses on Chemistry or Physics that students will take their junior year. With successful completion of physical science, biology, physics or chemistry, students at Greenville High School meet science graduation requirements.

In this introductory course, students were exposed to a wide range of topics related to Chemistry and Physics. The first semester was spent studying Chemistry and the second semester was studying Physics. The scope of the topics and sequence are shown in Table 2 for the second semester course. All of the units included labs as part of the instruction; however, the three shaded were those implemented in the data collection for this thesis.

Table 3 Greenville Introduction to Physics: Scope and Sequence

2nd Semester Outline	Introduction to Physics –Scope and Sequence
Unit 1	Forms of Energy
Unit 2	The Study of Motion
Unit 3	The Study of Forces
Unit 4	Electrical Energy
Unit 5	Heat Energy
Unit 6	Wave Energy

Table 3 (cont'd)

Unit 8	Electromagnetic Spectrum
Unit 7	Sound Energy

The students experienced a variety of instructional practices throughout the semester including lectures, demonstrations, guided inquiries, activities, laboratory based inquiries, videos, guest presentations, and field trips. A grading system was employed that reflected this teaching approach which included the use of a highly developed rubric for lab activities (Appendix 3). The focus of the research reported here highlighted scientific practice and laboratory based inquiry.

Based on the Fisher (2006) model, the researcher developed appropriate lab activities in the summer months of 2013 at Michigan State. To construct the best possible model, outcomes for students were assessed with input from colleagues. Time and thought were needed to develop student activities and assessments to encourage independence. Colleagues reflected on the success of each targeted lab. As a result, modifications or changes were implemented. Some changes took place to enhance comprehension while successful techniques continued to be used.

Approval was granted from the Greenville High School principal and the Institutional Review Board at Michigan State University (Appendix 11) for this project. Parental consent was required for students to be considered subjects in this study. Each student was given a consent form (Appendix 1) and asked to return it in a sealed envelope to the office. Of the two classes numbering 56 students, 20 students completed all additional requirements and had acceptable attendance.

At the beginning of this study, all students were given a pretest (Appendix 2) to establish baseline data and proficiency level on the selected learning objectives.

The following learning objectives provided a written description of the skills that students needed to demonstrate in order to be considered proficient in using the scientific method for the *Introduction to Physics* classroom. These objectives reflect what is required to accurately summarize and use the scientific method. Each objective was listed and accompanied by a basic description of what the evaluator used for scoring on a pretest and posttest. (Appendix 3). A posttest assessment (Appendix 2) followed the third laboratory unit, that measured progress in meeting these learning objectives.

When a student demonstrated proficiency for an objective, it was scored as two points. If the student described the concept, but was not able to provide an accurate example he or she was given one point. If the student had no relevant knowledge or no attempt was made, he or she received no points.

The six learning objectives are as follows:

A. ***The student will be able to write a question about an observation.*** The question must be relevant to the observation, must be at least one written sentence, and be testable.

B. **The student will be able to write a hypothesis.** The hypothesis must relate to the observation and question designed in Learning Objective A. Further, the hypothesis must be easily testable by the student. Students write their hypotheses as complete sentences.

C. **The student will identify controls/variables that might influence his/her hypothesis.** The student must list four factors that could be considered controls or variables in the investigation of their hypothesis, as defined in Learning Objective B. The four factors could be either controls, manipulated or responding variables.

D. **The *student will set up an experiment to test his/her hypothesis*.** The experiment must be described in such a way that the evaluator could perform the same procedural steps and expect the same outcome. This would probably include a list of the steps the student takes to conduct his or her investigation. The steps would indicate measurements such as quantity, mass, temperature, etc. The student might also include qualitative data such as cloud cover, color, or other immeasurable factors.

E. **The student will collect and analyze data while conducting his/her experiment.** The student will conduct the experiment, run trials, collect data, and record data using tables, graphs, or other appropriate measures. The student will provide an adequate written description that summarizes the meaning of his or her data.

F. **The student will write a statement that indicates a claim with evidence and reasoning.** The student will need to indicate an answer to his or her investigation question as defined in the Learning Objective A-this is a claim. Further, the student will need to reference the data (Learning Objective E) that supports his/her claim. Finally, the student will explain how/why the evidence supports the claim.

The focus of this research was to document student performance in regards to these learning objectives over the course of 18 weeks as measured by three inquiry labs write-ups (Appendix 4-6). The instructor expected that this would be a sufficient number of labs spaced throughout the semester and would not hamper completing all content areas. The reason the specific units were chosen was that each of the labs was relatively easy to transition to the gradual release format as displayed earlier in Figure 4 by Fisher (2006). Each write-up was assigned after the student completed a lab/activity where he/she was given instruction on the scientific practices that are used to teach inquiry at Greenville High School. These write-ups measured the six selected learning objectives as previously described. Further, the students were given increasing responsibility for completion of each lab. This procedure will be explained in more detail as the activities are described.

The instruction of each unit followed a general format. Vocabulary terms were given as an introduction to terminology to be used in the unit. The student looked up the definitions to the terms and wrote them out using their glossary definitions. These terms were used for a quiz at a later date in the unit. Power point notes or an outline was provided to the students which covered the lecture aspect of the unit. Each day new material was added to the growing body of material that was added to each note taking session. Each unit was broken down into manageable chunks so that students were able to apply the new information to a reinforcement exercise which was a daily assignment. Homework was referred to as daily work and seat time was used for its completion. These assignments were then either graded by the instructor or covered using a digital white board to display student answers and instructor corrections. Unit tests were generally given at the end of a unit after a review and question time is given. Labs are dispersed amongst the daily routine and there is usually one or two labs per unit.

The first lab in this study was called *Study of Motion*. (Appendix 4) Its emphasis was on the Scientific Method and was intended to teach the concept of science as a process. Students were closely guided throughout this activity. Therefore, this lab would be considered a directed inquiry lab. Because the first unit was scientific inquiry, the students received a significant amount of teacher directed content instruction, using the Communities of Practice model as developed by VanAndel Education Institute. The lesson itself also promoted the values of repetition and prediction in doing science. Question prompting was used heavily in this lab. It also included instructor modeling and scaffold learning for the students. In addition, it was also made known that for this lab, instructor involvement would be major, but decreasing as experience increased.

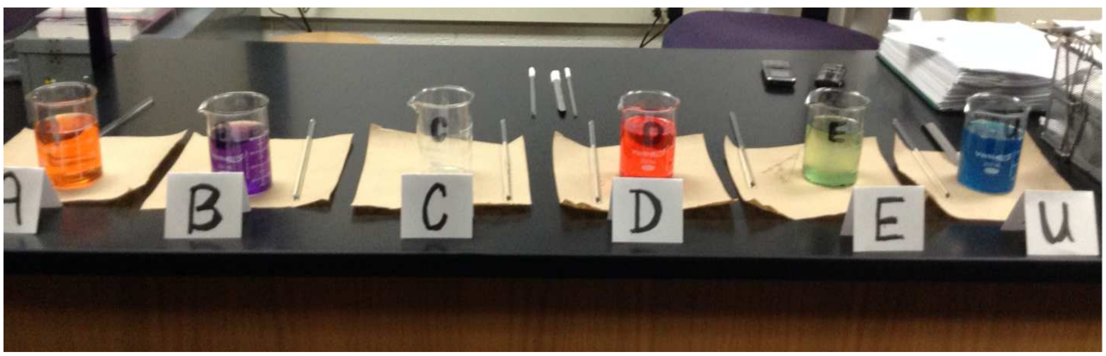
The second lab was called *Heat Transfer* Lab (Appendix 5) and addressed insulators and conductors.

Figure 5 Heat Transfer Lab: Students at Work

In following the form of gradual release, students were expected to play a more meaningful role in their learning (Figure 5). Active questioning was encouraged and the students were more actively involved than previously, as demonstrated by the amount of active hands on procedures they were left to develop themselves. Students were given the choice of multiple secondary articles made available for resource information by the instructor. The group members then decided which article contained the most useful information to be used in their final write-ups.

The third and final lab for this study (Figure 6) used to measure student progress and understanding the process of science was called *Study of Waves* (Appendix 6).

Figure 6 Wave Energy Lab: Experimental Set Up



Students followed guidelines that were set out for them. More independence from direct instruction was emphasized. Students were expected to find information supporting suggested hypotheses on their own initiative. Completion of this lab was to be expected in a more timely manner compared to prior labs.

Technology was brought into this third lab to enhance the gradual release model. A frequency analyzer was used to determine the sound wave frequencies of various solutions. This mobile device was handheld and used to record the wave frequencies that are obtained from striking a glass beaker filled with an unknown liquid solution. It also determined wave frequency in Hertz.

Because all investigations in science involve similar basic components, each time a student experienced a lab, he or she was required to complete the six learning objectives that were addressed in the initial lab. The gradual release model was used in all three of the labs. For each consecutive lab, higher expectations were placed on the students. In this manner students were taking control of their own learning in making predictions, setting up and controlling experiments, analyzing and interpreting data, and deciding whether or not to accept or reject their own hypothesis.

After the ten week period used for class instruction and labs, a separate day was used for the post test (Appendix 2) and the student survey (Appendix 8). Discussion and student remarks were made concerning the class content and application of labs. Some implied that the labs began to get easier with more experience with the model. Further expansion of student comments are noted in the Discussion section of this thesis.

RESULTS AND EVALUATION

There were sixty possible candidates for this study. However, due to lack of completion of work, student absences, or refusal to participate, the number of participants was limited to twenty. Three separate analyses were examined in this thesis.

Pretest/Posttest Results:

Eligible students completed the parental consent form (Appendix 1), completed all class materials and turned in all lab work for the comparison using data analysis. Identical forms of the pretest/posttest were used (Appendix 2). The students were required to complete questions on the pretest/posttest using their own thinking skills in determining the best logical answers. The range for each objective was scored on a 0-2 point scale value. These were analyzed using a rubric (Appendix 3). Factors used to score these questions were noted in the rubric. The scores were analyzed to determine statistical differences between pretest and posttest scores, using a paired t-test (http://www.physics.csbsju.edu/stats/Paired_t-test_NROW_form.html). Pretest and Posttest data are shown in Table 4.

Table 4 Comparison of Pretest/Posttest Raw Score Results

Student Number	Pretest	Posttest	Difference
1.	8	8	0
2.	10	12	+2
3.	10	11	+1
4.	12	12	0
5.	7	8	+1
6.	11	12	+1

Table 4 (cont'd)

7.	**7**	**12**	**+5**
8.	10	7	-3
9.	**11**	8	-3
10.	10	12	+2
11.	8	10	+2
12.	10	12	+2
13.	9	9	0
14.	7	9	+2
15.	11	12	+1
16.	7	11	+4
17.	9	8	-1
18.	6	9	+3
19.	9	12	+3
20.	9	8	-1
	75.4%	**84.16%**	

This comparison generated a **P- value of < 0.035** (Table 5). This result was the analysis of the mean pretest and posttest scores of all 20 subjects. Using a statistical value of 0.05 level of significance as a threshold, this difference was statistically significant.

Table 5 Group Statistics: Pretest/Posttest Analysis Scores

	N	**Mean**	**Standard Deviation**	**Range (Points)**	**Percentage Scored**	**Probability Assuming Null**
Pretest	20	9.05	1.67	6.0-12.0	75%	
Posttest	20	10.1	1.86	7.0-12.0	84%	
						P- value of < 0.035

Most students improved their post test performance; however, twenty-five percent of the 20 students did not improve. An examination of the average scores showed the students' scores increased from 75% to 84%. Based on pretest performance, the maximum increase permitted was 25%.

Learning Objectives Analysis

Six learning objectives were used as criteria in determining scores for the students' pretest/posttests. Each objective was evaluated and scored on a 0, 1, and 2 point basis. Each objective was scrutinized according to how well the student responded. For example, student # 29, when asked the first pretest response evaluated by the LOA (Appendix 2): Make an observation of the above situation and ask a question about it. The student responded in the following manner," As the temperature increases in Celsius the number of clams goes up then down." This response received a point value of 1of 2 possible points since the student did not propose a question as suggested in the Learning objective. On the Posttest, the same student responded, "30 degrees Celsius is the highest developing clam. Why does the number of developing fertilized eggs decrease when the temperature gets cold?" In addition, student responses were also evaluated using the rubric in Appendix 3. This response received the maximum of 2 points.

Evaluation of data for all students participating is shown in Table 6. A threshold value of 0.05 was used to determine statistically significant differences on each objective.

Table 6 Data Analysis for Learning Objectives A-F Based on Paired T-Tests

earning Objective	N	Mean Pretest	Mean Posttest	Standard Deviation Pretest	Standard Deviation Posttest	Probability assuming null
A	20	1.80	1.75	.410	.550	.716
B	20	1.75	1.85	.444	.366	.330
C	20	1.75	1.70	.444	.571	.772
D	20	1.20	1.50	.523	.607	.137
E	20	1.15	1.75	.587	.444	.002 *
F	20	1.40	1.55	.503	.605	.330

*Statistically Significant

At the 0.05 level of significance, Learning Objective E was statistically significant. There was increased knowledge of the learning goal. Learning Objective E entailed the students' abilities to collect and analyze data, after conducting their lab experiments. This practice had increased significantly according to the pretest/posttest data. Though at least one other Learning Objective came close to being significant (Learning Objective D- setting up experiment to test their hypothesis), it did not reach the statistical required level. These results suggested several possible explanations and or hypotheses which will be brought up in the Discussion section of this thesis.

Gradual release of responsibility was also a primary objective of this study. Tables 4 and 5 noted the pretest/posttest differences of individual students. Sixty percent of the students based on pretest/posttest data improved, while twenty-five percent did not. Fifteen percent remained the same.

DISCUSSION AND CONCLUSION

The emphasis of this study was to assist students in developing a means for solving science questions as well as everyday problems that occur outside of the school setting. Too many times in the past science instructors simply allowed the students to complete lab activities and experiments without challenging them to use their own abilities. Teachers processed students through the sequence of the scientific method without them controlling their outcomes.

We have seen, through the development and changes of the scientific model, that history has influenced current models of inquiry.(Quigley, et. al, 2011). The scientific model as presented in schools started as a linear progression that had a very systematic and intentional order with little variation. This was seen in Boynton's Linear Progression Model (Figure1). The science education community now knows, believes, and implements processes in the multidirectional version as referenced in Figure 2, "How Science Works: The Flowchart Graphic".(How Science Works: The Flowchart Graphic in http://undsci.berkeley.edu/flowchart_noninteractive.php; Van Andel Institute $QPOE_2$ Inquiry Model, 2013).

In addition, Van Andel Institute for Science Education developed instructional models that allow for the gradual release of responsibility. This, in turn, led to more student ownership and self direction. Fisher and Frey (2013) indicated that by using a more intentional, incremental approach while expanding the student accountability, there can be an increase in background skills and knowledge.

The instructor's intentions for this study were to show the students that there was a proper way to “do” science. Actively participating as scientists in the classroom, practicing skills, and developing knowledge allowed for student gains in increased responsibility and scientific inquiry (Tables 4 and 5). Based on lab practice, scientific inquiry and gradual release provided focus to have students reach the desired outcome, becoming “true” scientists. Analysis showed a positive significant difference in Pretest and Posttest students’ scores. Observable behaviors in the classroom supported the findings overall. The students had changed their patterns of questioning and strength of questions while determining outcomes. Depth of knowledge in the given expectations also increased.

For informational purposes, the format of the three labs was similar (Appendices 4-6). By using a modeling process when completing these labs, I was able to actively control the amount of gradual release in the classroom setting. For example one might compare this teaching model to the learning involved in riding a bike. I held onto the seat as they learned to gain their balance (understand terminology and expectations) and pedal (try to hypothesize and experiment without retribution) to keep their balance. As they pedaled faster through labs two and three, they learned that they could be in charge of their own understanding and ideas. Without this opportunity to explore and fail, there would be few gains.

For the Study of Motion Lab (Appendix 4), teacher directed instruction was used. Many prompting questions were used and the students were directly led through all sections of the lab. Pre-lab discussion of background information was given in advance of the laboratory exercise. Basically, this consisted of handouts, preselected articles from the instructor, note taking, vocabulary exposure and varied classroom exercises to ready the students for the lab work.

A second lab, The Heat Transfer (Appendix 5), involved student input to a greater degree. Each time students completed labs, fewer oral directions and less material was provided for them. They were expected to initiate their own questions, responses and knowledge probes. This lab involved them choosing from a teacher selected group of articles, which provided additional information for their conclusions. After reading their selected article, students were to share newfound ideas and facts with the other three members of their group. The students were observed making their own discoveries and sharing with their peers. This intermediate process gave the students confidence and more control, something they appeared to desire. It also satisfied the goal of more student led discovery.

In the third and final lab, The Study of Waves, students picked their own secondary knowledge resources. These resources were used for the background information to supplement the students' prior knowledge about waves. Attaching this resource to their lab was part of the scoring rubric when evaluating the third lab activity. As shown in student lab reports (Appendix 7), the students were able to successfully complete and understand the relevant concepts.

As a class, students were required to develop their own experiments with their own procedural steps and their own analysis. The students increased in their ability to obtain knowledge of how to work through lab exercises. This ability should further assist them in the future as the development of the Van Andel Model occurs regularly throughout high school.

The success of this technique in the science classroom is difficult to measure. Pretest/Posttest and Learning Objectives allow for more objective data analysis. According to Ronald D. Anderson (2010), there is no silver bullet for inquiry. However, inquiry and gradual release do intertwine.

Classroom observation determined a positive difference in using gradual release in this study. Observable behaviors in the classroom supported the findings overall. In this period of time and with the three labs, the students came up with more of their own ideas than previously in more structured settings. Fewer leading questions by the teacher were needed. More examples were elicited from students near the end of the study. More collaboration took place within the classroom and in their small groups. More ownership in experimental set up and outcomes were observed.

Sandra Clark from the *English Teaching Forum,* (2014) noted that like scientific inquiry, gradual release is not a linear process. There needs to be a place for sufficient practice and guided instruction. Then this becomes, with lots of practice and trial and error, student centered instruction.

Several student comments were also interesting in considering the efficiency of gradual release: "The experiments were the only thing that jogged my brain (student # 20)." "We had to do a lot of thinking and come up with experiments(s) ourselves (student # 11)." "It was different and made me think (student #13)."

This study was not without its challenges.

Interpretation of pretest/posttest results indicated that there was a substantial increase in student performance. Several factors could have contributed to this increase. First, this was the second time that the students were exposed to these particular questions, so previous learning may have impacted results. One should note the instructor did not go over or deliberately teach this pretest before or after administration.

Second, the subjects were cognizant they were part of an experiment in a research project. Thus, some “halo effect” may have contributed to positive results. In addition, the instructor noted as time passed, the students became more comfortable with the classroom content and assessments.

Third, over the course of eighteen weeks, the students’ behaviors showed definite improvement in completing expected tasks, written assignments, lab activities, and other classroom activities.

However, there were difficulties with using only a limited number of hours in implementing these new concepts and conditions for student use. We had eight units for the semester and a limited amount of time was set aside for each. By focusing more time and greater emphasis on this model, the students would become more rehearsed in how to use it and expectations would become more normalized. Allowing time for middle school and the high school science staffs to meet would allow for open sharing of problems and allow for advanced discussion and best practices with the Van Andel model. Instructors could share their concerns and successes to all staff in terms of curriculum change and the values derived from gradual release. It has taken over three years to reconstruct approximately 50% of these labs with Scientific Inquiry and Gradual Release.

Subjective Impressions

According to Learning Objectives A-F, students were able to form a more independent approach to problem solving, although this was not substantial in the data that was recorded (Tables 4 and 5). An increase of approximately ten percent was substantial. Considering these are freshmen class students, the room for improvement in the next three years will be substantial if a similar setting and student motivation continue.

As a teacher, use and application of this type of learning was difficult to administer at the beginning but eased with experience. Although not always successful in the first or second attempt, increases were noticed in student comprehension and application with each succeeding lab and its write-up. I allowed the opportunity for students to challenge the norms of the classroom and its predictable behavior. For growth, students were allowed to make errors in the early labs. This was followed by discussion of common mistakes and misconceptions. In essence I had to allow the students to fail early in their attempts to allow them to experience more success later.

As a whole this experience has taught me that taking a chance on a new idea can lead to a positive outcome. Students like to actively participate and not just watch what goes on. By developing a model that has the students play an important role in their own learning, a sense of ownership takes hold and allows them to explore their own ideas which otherwise may have sat idle. This too should lead to better problem solving skills in the real world application as they will surely be faced with adversity. In closing I posed a question to my students asking for their independent thoughts on how the whole QPOE model labs and Gradual Release ideas affected them (Appendix 10)

Q: How did you like the labs as a whole? What other things could we have done differently to make learning more enjoyable?

"As a whole they were a good way to help us understand the units. I liked them. You could do more hands on stuff between labs. Otherwise, the class and learning was fun."

"Keep everything the same, I learned very well from these labs."

"I enjoyed all of the labs overall. I learned a lot of new things from them and I only had one small amount of confusion for reasons that had nothing to do with the labs given, But, my confusion dissipated after I realized my problem/concern."

"I loved the labs. They were fun and educational. These don't usually mix."

Even though the students had their own favorite labs, as indicated by the survey, we may have created a few more true scientists in the world.

APPENDICES

Appendix 1 Parental Consent and Student Assent Form

Dear Students and Parents/Guardians:

I would like to take this opportunity to welcome you back to school and invite you to participate in a research project, , which I will conduct as a part of the Physical Science program this Semester. My name is Mr. Trevor Schmachtenberger. I am your science teacher for the second semester and I am also a master's degree student at Michigan State University. Researchers are required to provide a consent form like this to inform you about the study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

What is the purpose of this research? I have been working on effective ways to teach our Scientific method unit, and I plan to study the results of this teaching approach on student comprehension and retention of the material. The results of this research will contribute to teacher's understanding about the best way to teach about science topics. Completion of this research project will also help me to earn my master's degree in Michigan State University's College of Natural Science.

What will students do? Students will participate in the instructional unit about the Scientific Method. Students will complete the usual assignments, laboratory experiments and activities, class demonstrations and pretest/posttest just as you do for any other unit of instruction. There are no unique research activities and participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of student's work for research purposes. This project will take place in Fall of 2013 and continue throughout the first marking period (9 weeks). I am asking for permission from both students and parents/guardians (one parent/guardian) is sufficient) to use copies of student work for my research purposes.

What are the potential benefits? My reason for doing this research is to learn more about improving the quality of science instruction. I won't know about the effectiveness of my teaching methods until I analyze my research results. If the results are positive, I can apply the same teaching methods to other science topics taught in this course, and you will benefit by better learning and remembering of course content. I will report the results in my master's thesis so that other teachers and their students can benefit from my research.

What are the potential risks? There are no foreseeable risks associated with completing course assignments, laboratory experiments and activities, class demonstrations, and pretest/posttests. In fact, completing coursework should be very beneficial to students.

Another person will store the consent forms (where you say " yes" or "no") in a locked file cabinet that will not be opened until after I have assigned the grades for this marking period. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all of the written work. Later I will analyze the written work for students who have agreed to participate in the study and whose parents /guardians have consented.

How will privacy and confidentiality be protected? Information about you will be protected to the maximum extent allowable by law. Student's names will not be reported in my master's thesis or in any other dissemination of the results of this research. Instead, the data will consist of class averages and samples of student work that will not include names. After I analyze the data to determine class averages and choose samples of student work for presentation in the thesis, I will destroy the copies of student's original assignments, tests, etc. The only people who will have access to the data are me, my thesis committee at MSU, and the Institutional Review Board at MSU. The data will be stored on password-protected computers (during the study) and in locked file cabinets in Dr. Heidemann's locked office at MSU (after the study) for at least three years after the study.

What are your rights to participate, say no, or withdraw? Participation in this research is completely voluntary. You have the right to say "no". You may change your mind at any time and withdraw. If either the student or parent/guardian requests to withdraw, the student's information will not be used in this study. There are no penalties for saying "no" or choosing to withdraw.

Who can you contact with questions and concerns? If you have concerns or questions about this study, please don't hesitate to contact:

Mr. Trevor Schmachtenberger Greenville High School 111N. Hillcrest Greenville Mich. 48838 schmacht@greenville.k12.mi.us	Dr. Merle Heidemann 118 North Kedzie Lab Michigan State University East Lansing, Mich. 48824 heidma2@msu.edu 517432-2152x107

If you have questions or concerns regarding your role as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if desired, MSU Human Research Protection Program at: **irb@msu.edu**

How should I submit this consent form? Please complete the attached form. Both the student and parent/guardian must sign the form. Please return with your student a form indicating interest either way. Please label on the outside the following information:

Consent Form: Trevor Schmachtenberger
Greenville High School: Science Department

Parents/guardians should complete this following consent information:

I voluntarily agree to have ________________________________ participate in this study.
(Student Name)

Please check all that apply:

Data:

______ I give Trevor Schmachtenberger permission to use data generated from my child's work in class for his thesis project. All data shall remain confidential.

______ I do not wish to have my child's work in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in this research.

Photography, audio taping, or videotaping:

______ I give Trevor Schmachtenberger permission to use photos, or videotapes of my child in the class room doing work related to this thesis project. I understand that my child will not be identified.

_______I do not wish to have my child's images used at any time during this thesis project.

Signatures: ______________________________________ _________

(Parent Signature) **(Date)**

______________________________________ _________

(Student Signature) **(Date)**

Appendix 2 Pretest/Posttest for Scientific Inquiry

Name___________________ Hr. ___

Use the following data/ information to answer the questions to follow.

A clam farmer has been keeping records concerning the water temperature and the number of clams developing from fertilized eggs. The data are recorded below.

Table 7 Data for Water Temperature and Developing Clams

Water Temperature in Degrees Celsius	Number of Developing Clams
15	75
20	90
25	120
30	140
35	75
40	40
45	15
50	0

1) Make an observation of the above situation and ask a question about it.

____

____

2) Propose a Hypothesis for the situation listed above.

____

____

3) Identify four controls/variables that might influence your hypothesis.

____

____

4) Setup an experiment that will test the hypothesis that you came up with.

5) Provide a written description that summarizes the data in the example given.

6) Provide Claim-Evidence-Reasoning for determining the accuracy of the Hypothesis.

Appendix 3 Rubric for Pretest/Posttest

The following Rubric served as a guide for determining Pretest/Posttest scores. This could also serve as a guide to labs in the future.

Table 8 Learning Objective Rubric

Section	**Description**	**Point Value**	**Student Score**
Learning Objective **A**	Relevant, one sentence, testable	0-2	
Learning Objective **B**	Hypothesis relates to observation, testable, full sentence	0-2	
Learning Objective **C**	List 4 factors that are controls or variables.	0-2	
Learning Objective **D**	List of steps, producing same outcome.	0-2	
Learning Objective **E**	Collect and analyze the experiments data. Put into summary.	0-2	
Learning Objective **F**	Provide an answer with support. Show results.	0-2	
		Total Score	

Appendix 4 Lab 1: Study of Motion

Name ___________________________________

Velocity and Acceleration

Goal: Illustrate and perform an example of constant velocity. Show me what constant velocity looks like.

Knowledge Probe:

Prior/Personal Secondary

(speed, velocity, acceleration, formulas, graphs)

Figure 7 Knowledge Probe Information

•	•
•	•
•	•
•	•
•	•

Guidelines:

There is a 30 meter course marked off in 5 meter increments.

Groups consist of 7 people.

Develop the investigation plan (numbered, step by step directions).

There are enough timers for each member of your group.

Observe and record all data, including qualitative data.

Investigation Plan: attach lined paper

Observations:

Once all data is collected…

Question: DID YOU MOVE AT A CONSTANT VELOCITY?

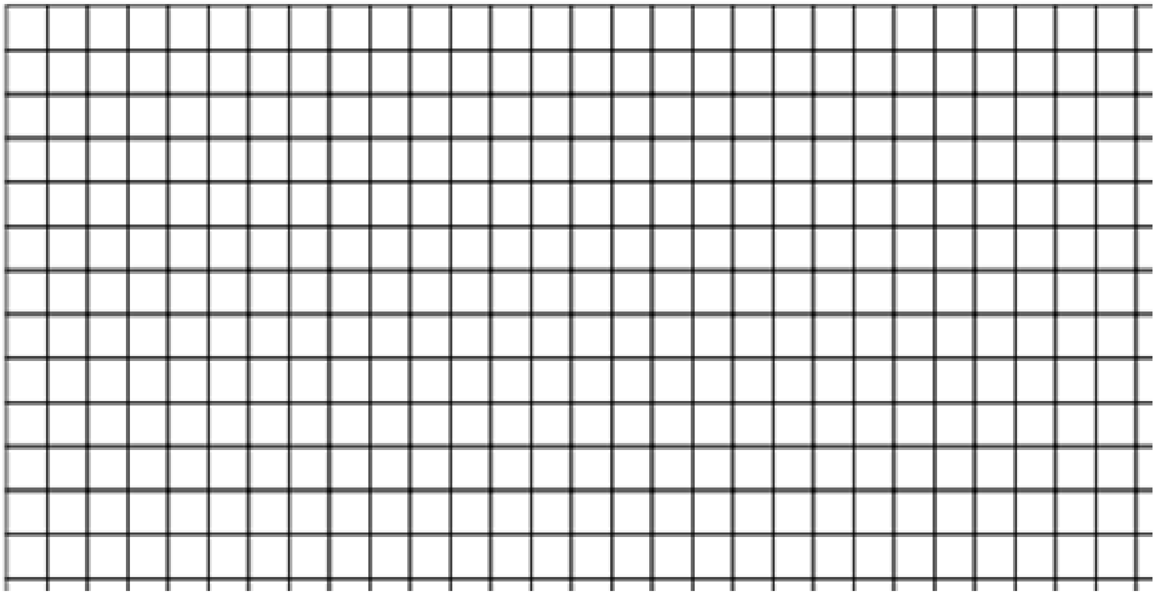
Prediction: I predict ____

because ____.

Data Analysis: Graphs & Calculations

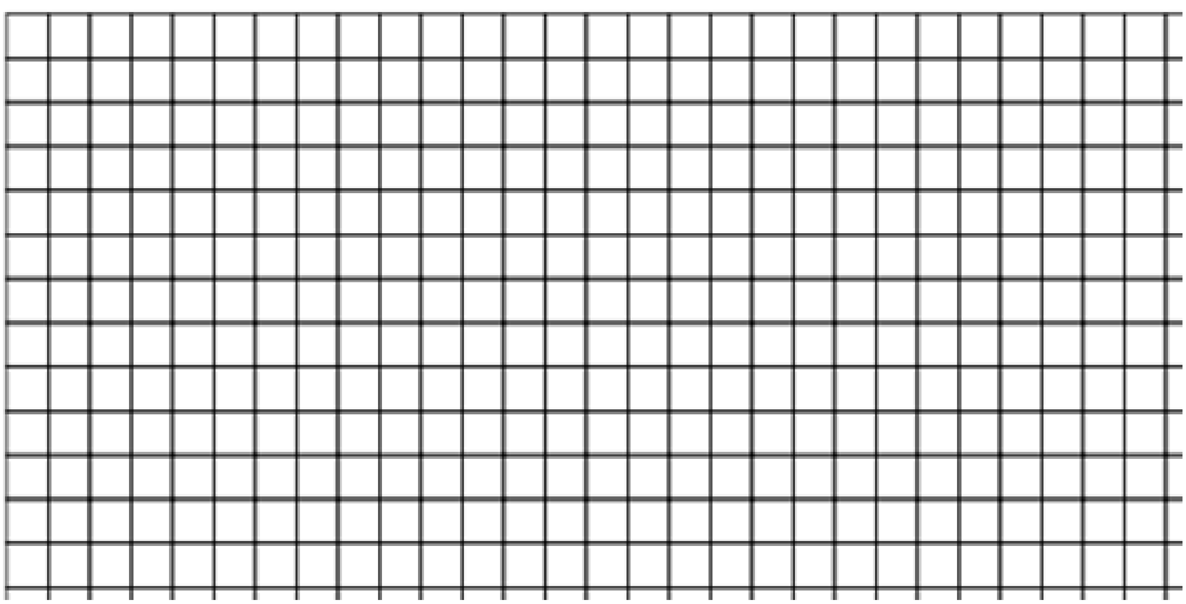
Two graphs: **Distance vs Time** and **Speed vs Time**

Figure 8. Distance vs. Time Graph



Calculations –

Figure 9. Speed vs. Time Graph



Data Analysis Summary - ____

Explanation:

Claim –

Evidence –

Reasoning –

Prior Knowledge -

Fair Test -

Science Concepts -

Knowledge from Others -

Evaluation:

What are the sources of error?

What would you do differently next time?

How confident are you in your results? (see confidence chart)

What surprised you?

Appendix 5 Lab 2: Heat Transfer Lab

Name ____ Date ______________________ Hour _____

Question:

What materials are insulators and what materials are conductors of heat energy?

Figure 10. Student Knowledge Probe

Prior Knowledge	Scientific Ideas (Research/Article) Knowledge
• • • • •	• • • • •

Prediction:

I predict ____ are heat insulators and ____ are heat conductors because ____

____ ______.

Investigation Plan:

1. Put 200 ml of hot water into the aluminum can.
2. Measure the initial temperature of the water and record at time 0.
3. Start the timer and begin to gently stir the water.
4. Measure and record the temperature of the water every minute for 5 minutes.

5. When you are not measuring, constantly stir the water.
6. When the five minutes are up, dump out the water.
7. Repeat the process with the foam cup, plastic cup, and the glass beaker.

Figure 11 Observations of Data

Time (minutes)	Aluminum	Foam	Plastic	Glass
0				
1				
2				
3				
4				
5				

Data Analysis:

Calculate the amount of energy lost by the water from each type of container.

Heat Energy Lost = mass of water x Δ temperature x specific heat

- 1 ml of water has a mass of 1 gram so 200 ml is _____________ grams
- T is the change in temperature and ΔT=final temperature - initial temperature
- specific heat capacity of water = 4.18 J/g °C

Figure 12 Data Analysis

Container Material	m = mass (g)	ΔT = Tf-Ti (°C)	C=specific heat (4.18 J/g °C)	Heat Lost (J) $\Delta H = m \times \Delta T \times C$

Data Analysis Continued:

Create graphs illustrating the results of your investigation. Be sure to include: title, color coded key, labeled axises, numbered increments, and easy to read lines or graphs.

Figure 13 Graph One

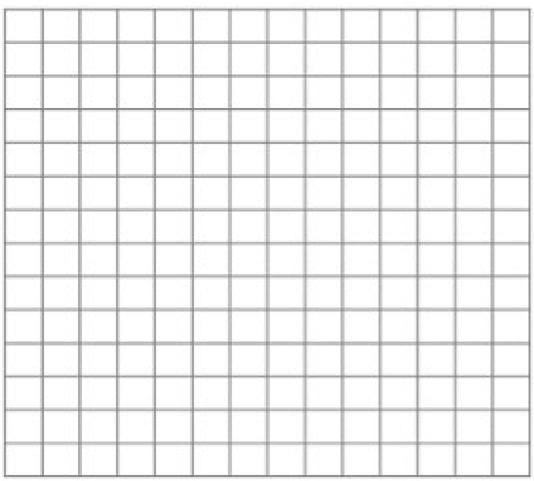
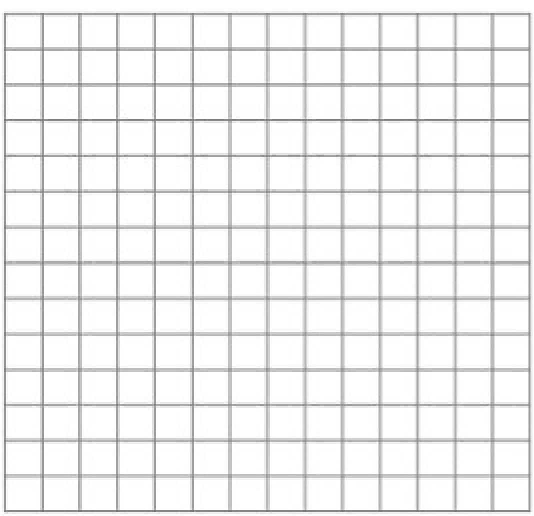


Figure 14 Graph Two



Data Analysis Summary: Based on the data and graphs, summarize the data.

1. What material lost the most heat energy and how do you know?

2. Which material(s) appear to be heat conductors and how do you know?

3. What material lost the least heat energy and how do you know?

4. Which material(s) appear to be heat insulators and how do you know?

Explanation---Graphic Organizer

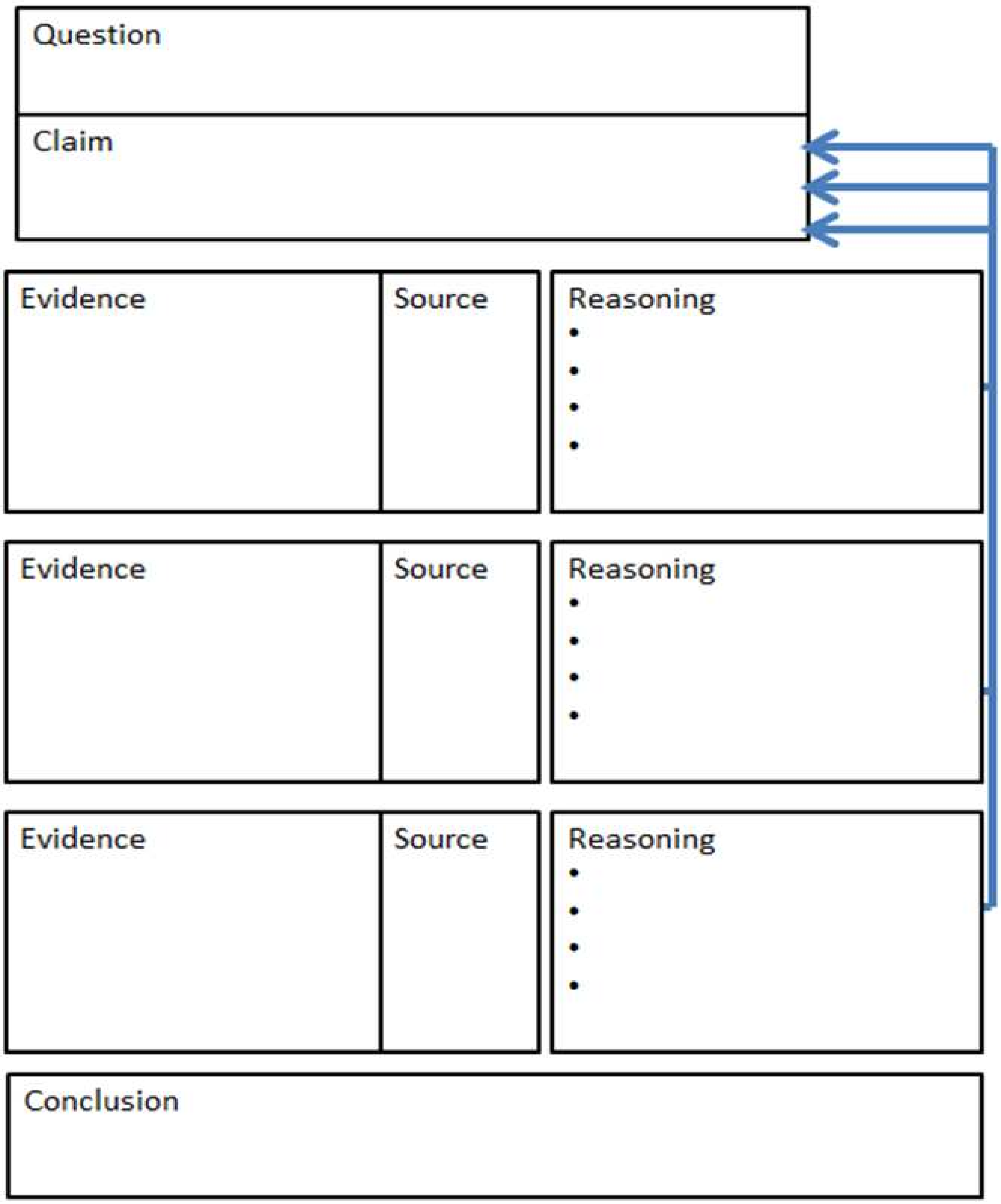
A claim is an answer to our lab investigation's question (see front page).

Evidence includes data/numbers from tables and/or graphs (source).

Reasoning includes:

- explanation of why your data is valid evidence
- connection to scientific ideas (knowledge probes)
- ideas and evidence from other groups
- support of why your test was fair/trustworthy or not

Figure 15 Step Organizer



Explanation: (see graphic organizer)

In paragraph format, write a claim (answer) to our lab investigation's question (see front page).

Support your answer with evidence (data/numbers from tables and graphs).

Explain your evidence with reasoning (why it's valid, if it's trustworthy, connect to science & others).

Evaluation:

1. What are the sources of error in your investigation?

2. What could you do better next time?

3. How confident are you in your results <u>and why</u>? SEE CONFIDENCE CHART!

Application:

1. What material, from those studied in our investigation, might you choose for keeping your drink cold on a hot summer day? Why?

2. How might the materials in a home, think of those studied in our investigation, affect heat loss in the winter? Why?

Appendix 6 Lab3: Study of Waves

Name ________________________ Date __________ Hour

Goal: How does the movement of sound waves through different materials affect the sounds we hear? Notice the variations in sound when waves travel through different materials. Infer what property of the materials cause the sound waves to produce different sound.

Knowledge Probe: What factors affect the speed of sound? What is the order of increasing **density** of the materials that you are testing?

Prior/Personal | Secondary (your article or research)

Figure 16 Student Knowledge Probe

•	•
•	•
•	•
•	•
•	•

Guidelines:

150 ml beakers (5)

water

corn syrup

vegetable oil

Other (?)

pencil

Investigation Plan: attach lined paper

Data and Observations:

Sound Waves through Materials (Time or pitch)

Figure 17 Material Data

Beaker	
Water	
Vegetable Oil	
Corn Syrup	
Empty	
Other substance	

Once all data is collected…

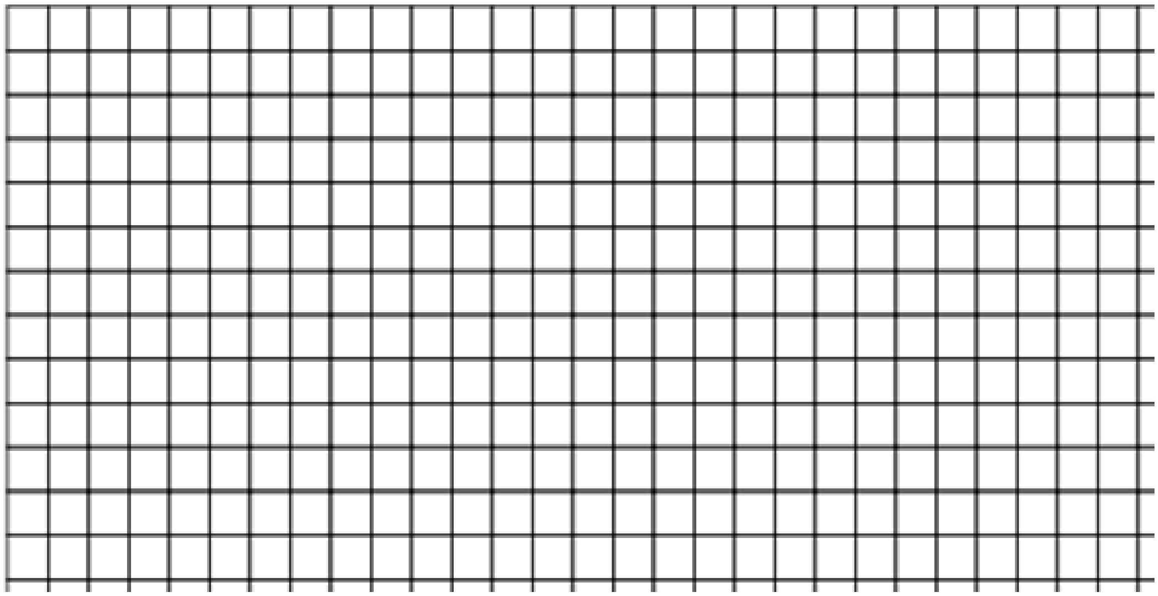
Question: Did you hear a difference in the matter.

Prediction: I predict ____

because ____.

Graph what you think the sound of each matter would look like as the waves are transmitted through it.

Figure 18 Sound Wave Graph



Data Analysis Summary - ____

____

____

____

____

____

____

Explanation:

Claim –

____

____

____

Evidence - ____

____

Reasoning –

Prior Knowledge -

____

____

____

Fair Test -

____

____

____

Science Concepts -

____

____

____

____

Knowledge from Others-

____

____

____

____

Evaluation:

What are the sources of error?

____

____

____

What would you do differently next time?

____

____

____

How confident are you in your results? (see confidence chart)

____

____

____

What surprised you?

____

____

____

____

Conclude and Apply

List the materials in the beakers in order of increasing density.

____

____

____

____

Infer how the pitch of the sound changes as the density of the material in the beaker increases.

____

____

____

____

How does the density of the material in the beaker affect how long the sound continued to be heard after the beaker was tapped?

Appendix 7
Survey for Mr. Schmachtenberger's Labs used in Scientific Method Unit

This survey will aide Mr. Schmachtenberger in gathering information on student opinions of the labs that were used throughout this unit. Your responses will remain with me and no one else. Answer the questions truthfully and think before writing an answer.

Which of the activities in this unit did you enjoy the most?

Which of the activities do you feel you learned the most from?

Which activities made you think the most, you had to apply your brain to the application?

How did you enjoy designing your own scientific method lab for paper towels?

What did you like most about this unit in general?

On a scale of 1-5 (1= low with 5 = highest score)

How prepared were you for the pretest that was given? ______

How prepared were you for the posttest that was given? ______

How well do you think that you know the scientific method? ______

Did you enjoy the three labs that were completed in the first unit ______

Rank in order the labs (place a 3 by your favorite lab)

Take into account:

- Interest – did you enjoy the activity as we worked

- Confusion – were instructions hard to follow, or not enough information
- Time allowed to complete – too much or too little

Table 9 Activity Ranking Table

Score (3-1)	Lab Name	Please suggest how to make it better.
	Velocity and Acceleration	
	Heat Transfer Lab	
	Wave Energy Lab	

How did you like the labs as a whole? What other things could we have done differently to make learning more enjoyable?

____

____

____

____

Appendix 8

Figure 19 Draft for Students-----$QPOE_2$ Investigation Rubric for Labs

Goal: This is what we are trying to do.

Knowledge Probe (5 points) boxes are filled in completely - This indicates what I already know about a subject including secondary information from an outside source.

Guidelines (Given): These are the given instructions/details of your experiment and what information you have to work with. Included in this are the materials needed for the discovery.

Investigation Plan (3 points): The detailed information piece that describes in detail how I will proceed with the investigation. It leaves nothing to the imagination and everything is written out in well established steps. 10 steps for this motion lab. Repeatable, possibly drawings, all things clear and controlled.

Observations (**3 points**) – Data table is set up in a neat orderly fashion that makes sense

Contains, labels, units, data….

Quantitative (numbers) actual data

Qualitative- descriptions using your 5 senses

Question:

Prediction/Hypothesis (2points) - The main idea of my investigation. The question is what I want to know. Serves to guide my investigation. Is it humanly possible and if so, explain why.

Data Analysis Graphs and Calculations—

Graph (**5 points x number of graphs**) Clearly shows title, labels units, lines and or plots. Color lines and points may be taken into account. Neatness and using the entire graphing area are taken into account.

Calculations (2 Points) Show your work, Formula and calculations were shown on the lab or attached sheet indicating the student understands how to collect and calculate data.

Support: (2 points each segment)

- **Claim –** Answer to the question --**Claims** are statements that answer your original question. The stronger the better. No weak statements allowed!!!!
- **Evidence –** Refer to the graphs and data tables and put your personal explanation on the data that you have collected. The **evidence** is all of the scientific data that supports your claim. The claim is usually one sentence in length. It must be accurate, specific, and completely answer the question.
- **Reasoning – Reasoning** is the explanation that connects your claim to the evidence that supports it. It shows why the data you chose counts as evidence.

Explanation (1 point each per question) acts as a "conclusion" of your experiment. Incorporate all of the following in your explanation if you want full credit…..

- Prior Knowledge
- Fair Test
- Science Concepts
- Knowledge from Others

Evaluation (1 point each per question)

- What are the sources of error?
    - ✓ *How would you correct anything that you think went wrong?*
- What would you do differently next time?
    - ✓ Could you have done this experiment better and if so, how?
- How confident are you in your results?
    - ✓ A strong argument or hypothesis has good background support.
- What surprised you?
    - ✓ Anything you did not expect?

Group participation (5) - Teams constructively worked together to form a planned procedure and followed through on it.

Appendix 9

Results of: Survey for Mr. Schmachtenberger's Labs Used in Thesis Exploration

All students in my classes completed the in-class survey and questionnaire form. Students were asked the following questions; and answers varied per student.

Table 10 represents the student responses to three questions. Note that not all twenty students responded to each question. In interpreting the table, student reactions varied.

Table 10 Student Survey of Lab Activities

	Motion Lab Activity 1	**Heat Lab Activity 2**	**Waves Lab Activity 3**
Which of the activities in these units did you enjoy the most?	1	7	8
Which of the activities did you feel you learned the most from?	4	6	5
Which activities made you think the most, you had to apply your brain to the application?	8	2	6

In Table 11, students were asked a series of questions regarding their preparedness and reaction to the scientific method. Scores ranged from a low of 1 to a high of 5.

Table 11 Student Survey of Preparation for Pretest/Posttest and Use of Scientific Method

	1 -Low	2	3	4	5 - High	Out of 20
How prepared were you for the pretest that was given?	4	3	5	3	5	20
How prepared were you for the posttest that was given?	0	2	3	9	6	20
How well do you think that you know the scientific method?	0	0	7	9	4	20
Did you enjoy the three labs that were completed in the Semester unit	3	1	4	6	5	20

The instructor requested the students to rank order the 3 labs. In Table 12, interestingly Lab 3, The Study of Waves, was the students' favorite.

Table12 Preference Rank Order of Labs

Score (3-1)	Lab Name	Please suggest how to make it better.
Average 1.31 (25/19)	Velocity and Motion	Group comparison of results, more trials Maybe do it on the track next time
2.26 (43/19)	Heat Transfer Lab	Have you pick our partners Like it the way it is Use more containers Too little time, Funnest lab we experimented with conduction, do not change.
2.53 (48/19)	Wave Frequency Lab	Overall good… Use other containers, not just beakers Interesting and fun… Perfect, we took notes and did some experimenting…..

What did you like most about this Semester in general?

- Interest – did you enjoy the activity as we worked
- Confusion – were instructions hard to follow, or not enough information
- Time allowed to complete – too much or too little

Q: How did you like the labs as a whole? What other things could we have done differently to make learning more enjoyable?

<u>“As a whole they were a good way to help us understand the units. I liked them. You could do more hands on stuff between labs. Otherwise, the class and learning was fun.”</u>

<u>“Keep everything the same, I learned very well from these labs.”</u>

<u>“I enjoyed all of the labs overall. I learned a lot of new things from them and I only had one small amount of confusion for reasons that had nothing to do with the labs given, But, my confusion dissipated after I realized my problem/concern.”</u>

<u>“I loved the labs. They were fun and educational. These don’t usually mix.”</u>

Appendix 10 Greenville High School

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Voice: (616) 754-3681 • Fax: (616) &54-1994 • Website: www.Greenville.k12.mi.us/schools/ghs

Tuesday, July 23, 2013

Dear Mr. Steven Smith,

The purpose of this letter is to give my approval to Mr. Trevor Schmachtenberger to conduct his master's thesis research project, **An Inquiry approach to the Scientific Method**, here at Greenville High School for the 2013-2014 school year. I understand that this research poses no foreseeable risks to the students and that Mr. Schmachtenberger will take every possible effort to protect the identity of the students who volunteer to be a part of the study. If you have any questions or need to contact me for any reason, please email me at: wrightj@greenville.k12.mi.us or call (616) 225-1000.

Jeff Wright, Greenville High School Principal

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