EFFECTS OF QUESTIONING STRATEGIES ON STUDENTS' INQUIRY SKILLS DURING A PHYSICS RESEARCH PROJECT

by

Jessica K. Anderson

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

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2012

STATEMENT OF PERMISSION TO USE

Jessica K. Anderson

July 2012

TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND 1

CONCEPTUAL FRAMEWORK 2

METHODOLOGY 8

DATA AND ANALYSIS 13

INTERPRETATION AND CONCLUSION 32

VALUE 34

REFERENCES CITED 36

APPENDICES 38

- APPENDIX A: Student Understanding of Science, Scientific Inquiry, and Questioning Survey 39
- APPENDIX B: Nature of Science Rubric 47
- APPENDIX C: Questioning Rubric 49
- APPENDIX D: Nature of Science Interview Questions 51
- APPENDIX E: Teacher Field Notes Rubric for Brainstorming Activity 53
- APPENDIX F: Physics Research Journal Criteria 55
- APPENDIX G: Scientific Inquiry and Questioning Interview 57
- APPENDIX H: The Scientific Inquiry Questioning Interview Rubric 59
- APPENDIX I: I-Chart 61
- APPENDIX J: Questioning the Author 63
- APPENDIX K: Discovery Lab (Penny Tops Lab) 65
- APPENDIX L: Rebound Height 67
- APPENDIX M: Introduction to Energy Model PhET Lab 69
- APPENDIX N: Architecture of a Question Rubric 74
- APPENDIX O: I-Chart Interview 76
- APPENDIX P: The Scientific Inquiry and Questioning Self-Assessment Rubric 78
- APPENDIX Q: The Scientific Inquiry and Questioning Peer-Review Rubric..... 80

LIST OF TABLES

1. Data Triangulation Matrix Focus Question..……………………………………………13
2. Data Triangulation Matrix Focus Sub-Questions…………………………………….13
3. Pre-Treatment Results of Questions in the Society and Culture Section…………….17
4. Low Versus High Power Questions…………………………………………………..20
5. Percentages of High and Low Questions During Pre- and Post- Lab Questions…….22

LIST OF FIGURES

1. Observation and Inferences Modes..15
2. Student Opinions on Scientific Laws...16
3. Scientific Investigation Results..18
4. Percentage of High and Low Power Questions 22
5. Percentages of Student Self-Assessment and Peer-Reviews 25
6. Self-Assessment and Peer-Review Percentages: Processes of Science Section...........26
7. Cumulative Percent Change in Students' Inquiry and Questioning Skills 32

ABSTRACT

In this investigation, teacher and student questioning strategies were implemented within physics research projects with the intention of improving students' inquiry skills. Students involved in the study included 14 twelfth-grade physics students. Treatments within the study included introducing teacher modeled questioning strategies focusing on application, explanation, and recall and asking students to explain their thinking by asking *why* at the end of *yes* or *no* questions. A series of self-questioning models on cognitive processes were also introduced. Finally, students implemented the learned strategies while conducting their individual/partner research projects. Participants' questioning and inquiry skills were assessed with a series of surveys, recorded interviews, teacher field notes, and peer/self-assessments of their inquiry skills while conducting the research projects. The study revealed an increase in both students' questioning and inquiry skills.

INTRODUCTION AND BACKGROUND

For the past four years, I have been teaching science at Powell County High School in Deer Lodge, Montana. Deer Lodge is a rural, agriculturally-based community with a population of 7,180. Its ethnic population is made up of 95% Caucasian and 5% African American, Native American, Hispanic, and Other (United States Census Bureau, 2000). Powell County High School is a 9th-12th grade public school that serves a population of around 260 students (Montana Public School Enrollment Data, 2010).

Of those 260 students, I serve 14 in a yearlong physics course. In physics we cover five units: mechanics, states of matter, waves and light, electricity and magnetism, and modern physics. Throughout these units, students participate in group discussions, research projects, and inquiry-based laboratory investigations. These activities require students to use questioning skills through inquiry in order to investigate topics being covered. These experiences often lead to frustration among students because many lack the necessary questioning skills needed to fully engage in inquiry investigations.

Focus Question

Concern about students' questioning skills during inquiry activities led me to my primary focus question: How can I improve students' inquiry skills through questioning? Furthermore, I wanted to know if teacher modeling of questioning skills played a role in inquiry skill improvement, and if these skills could be improved through students' generating their own questions during activities and investigations.

CONCEPTUAL FRAMEWORK

Scientific inquiry is a diverse method of studying and understanding the natural world. It is defined as an activity that encourages students to observe, formulate questions, examine research sources, plan and conduct investigations, and communicate results of the experiment. It requires critical thinking, questioning skills, and the desire to observe and investigate (Inquiry and the National Science Education Standards, 2000). Inquiry teaching puts the power of learning science into the students' hands. By implementing inquiry activities and labs into classroom instruction, students are given the chance to build a knowledge base in science through their own experiences (BSCS, 2011; Jarrett, 1997). The embedded process allows students to build investigation, communication, and problem-solving expertise that will drive aspects of their everyday lives (Inquiry and the National Science Education Standards; Jarrett). However, without the incorporation of skilled questioning techniques by teachers and students, inquiry skills cannot meet their full potential. Questioning is one of the most vital tools to improve inquiry skills (Lin, Hong & Cheng, 2009; Good & Brophy, 1997). By modeling skilled questioning techniques, teachers can promote higher-levels of thinking and, in return, encourage students to use these skills to ask productive questions that will create a solid starting point for successful argumentation and explanation (Jarrett; Hall & Sampson, 2009).

Inquiry teaching is at the heart of thinking (Chin & Osborne, 2008). According to Elder and Paul (1998), questions drive thinking not answers. Questions guide the issues and problems students strive to investigate. They also demonstrate the level of thinking students are engaged in and whether this thinking leads to new insight. In inquiry activities, questions are meant to hook students' curiosity and to build interest in a topic. However, good questions do not solely stem from natural curiosity but from knowledge (Lucas, Bohanan, Broderick & Lehrer, 2005). Questions engage prior experiences and knowledge, therefore setting students up to do investigations, research, and then ask extension questions. However, it is rare that good questions fit into a neat box with clear answers. Questions need to push the limits of thinking and inspire new questions, which drive new investigations. It is also important to note that once questions are established, students need to be able to reflect on the value of the questions. It is with this reflection that inquiry is launched and further student involvement in research can be promoted (Lucas et al., 2005). When students are given the chance to perform inquiry activities, questioning skills come into play and are essential to improving and doing inquiry (Pieczura, 2009; Lin et al., 2009).

One of the main ways to improve students' inquiry skills is through teacher question modeling. Many questioning approaches can be used by teachers depending on teaching style and needs in the classroom. Techniques such as HRASE (History, Relationships, Applications, Speculations, and Explanations), elaborative interrogation, self questioning, and use of Bloom's Taxonomy become more effective when the instructor is cognizant of learning objectives, of the context of questions, and of student response. (Chin & Osborne, 2008; Latham, 1997).

According to Latham (1997), HRASE is one technique used to model good questioning strategies. In this model, teachers work from confidence-building questions to progressively harder thought-provoking questions. For instance, the *history* question asks students to recall what happened during a particular lab or activity. Teachers then pose a question that encourages students to make a *relationship* connection between the activity and other topics. The information generated by students is then used by the teacher to generate a question that promotes *application* of the connections students have made from the comparison. A teacher may then use students' responses to ask questions that generate *speculation* and have them *explain* their results of the applications and conjectures. This particular strategy, although very structured, exposes students to an effective questioning technique that will eventually promote inquiry skills.

Another questioning technique that can be incorporated to help improve inquiry skills is elaborative interrogation. This particular strategy focuses on asking students *why* something happened instead of *how* or *when* in order to expose prior knowledge and experience, and build relationships between the information (Menke & Pressley, 1994). For instance, in an experiment done by Wood, Pressley, and Winne (1994), a control group of students were taught by their teacher to retort each factual statement with a *why* question. From the study, the researchers found that students who asked *why* questions were able to make better connections between prior understanding and new facts. Students are then prepared to perform investigations, do research, and then, finally, ask extension questions that improve inquiry skills (Lucas et al., 2005).

A third teacher modeling technique mentioned by Chin and Osborne (2008) to promote inquiry skills is providing students with self-questioning examples focusing on cognitive processes. This strategy emphasizes students being given examples of questions that focus on comparing, explaining, hypothesizing, predicting, analyzing, and inferring. The "use of such questions [have] the potential to direct students' thinking towards specific goals and sub-goals, and to focus attention on different related aspects of the task in question" (Chin & Osborne, 2008, p. 39). These examples also provide students with an illustration of types of questions that promote investigation and reflection during inquiry activities (Inquiry and the National Science Education Standards, 2001; Jarrett, 2009).

Although similar to providing self-questioning examples, Marbach-Ad and Sokolove (2000) suggest teachers give students questioning examples based on Bloom's Taxonomy. By providing students with these examples, students would be able to reflect on the quality of questions and be able to explicate higher level questions. Therefore, they suggest that four types of question examples should be provided and embedded in a teachers' questioning repertoire. They are questions based on misconceptions and misunderstandings, those that deal with definitions and can be looked up using a textbook resource, those that involve information beyond a textbook, but need explaining, and finally questions that promote higher-level thinking skills that enforce extended investigation and questioning (Marbach-Ad & Sokolove, 2000). No matter what type of teacher modeling questions or examples are embedded in instruction to improve inquiry skills, students need to be exposed to good questioning strategies that focus on the scientific process, not just the facts.

With various strategies embedded in instruction, students have the first skills necessary for generating their own questions. According to Osborne, Erduran & Simon (2004), building students' questioning inventory is achievable and necessary in order to promote learning. It is through their own questioning that students build understanding, become embedded in a learning environment supportive of inquiry, and begin to use higher-order thinking skills in their questioning repertoire. An “emphasis on students’ questions conveys the message that inquiry is a natural component in a variety of science disciplines and that questions need to be constantly raised” (Kaberman & Dori, 2009, p. 599). Therefore, in order to promote student questioning and formulate inquiry skills, teachers need to incorporate activities to help students practice, enhance, and use these skills. A few good examples are pre-lab and post-lab questions, I-Chart (Inquiry Chart), and questioning the author (Ogle, 2009; Jarrett, 1997; Polacek & Keeling, 2005).

Although teachers often use pre-lab questions as a chance to introduce new vocabulary and concepts, pre-labs can also be used to encourage students to ask questions about the upcoming experiment or activity. For instance, in order to help students practice asking good questions as modeled previously by the teacher, teachers can assign students to write three or more topic specific questions. The teacher may then assign students to come up with a question they feel will be answered during the lab. It is at this time teachers can help encourage students to focus on questions that are specifically linked to the experiment or activity (Polacek & Keeling, 2005). This type of activity in return puts the investigation into the students’ hands and promotes the incorporation of inquiry skills into the experiment (Jarrett, 1997).

To further promote inquiry, teachers can ask students to do post-lab questions and experimental proposals after a lab is complete. “The post-lab questions are designed to encourage students to reflect on what they accomplished in the lab investigation and to stimulate thinking about new questions that derive from the experiment” (Polacek & Keeling, 2005, p. 53-54). Teachers ask students to pose a new question based on their observations and to come up with an experiment that may answer the new question.

When this type of activity is implemented into a classroom, it shows students that investigations begin with questions and conclude with a fresh set of questions, which is the basis of doing inquiry (Lucas et al., 2005; Polacek & Keeling, 2005). It also reinforces good questioning strategies and implements teacher modeled techniques in the students' learning.

Another technique to stimulate students' questioning and inquiry skills is the use of I-Charts. An I-Chart is a graphic organizer that focuses on topic questions and what the student already knows about the topic questions. The student must then use a variety of sources to answer the questions. Once the student has found sources, they summarize their findings, write any interesting facts they've discovered, and finally pose new questions about the topic. This type of activity can be done individually or in a group to encourage collaborative inquiry (Ogle, 2009). I-Charts work to incorporate teacher question modeling, student questioning, and in turn improve inquiry skills.

A similar technique to the I-Chart is Questioning the Author. This strategy can be incorporated by teachers in order to arouse inquiry and promote deeper student questioning. For instance, students may be given a text which may be read as a large group or in small groups. As the students read, the teacher may periodically interrupt the students with a question. Some sample questions include, "what was the author trying to say in this section? What examples would you add? What was left out?" (Ogle, 2009, p. 60). As the students become more comfortable with questioning based on the teachers' model, they are encouraged to take a more direct role with the text. The students begin to take a more authoritative role with their questions (Ogle, 2009). This strategy, as suggested above, makes questioning and inquiry the students' responsibility.

Although questioning technique effectiveness may vary from classroom to classroom, when teachers design a classroom where students are engaged in questioning, they are sparking the curiosities of those students. Teachers are also helping their students build knowledge in a topic, helping implement strategies that will enhance inquiry skills in their everyday lives, and helping develop life-long learners through questioning technique development (Latham, 1997; Hall & Sampson, 2009; Lin, Hong & Cheng, 2009).

METHODOLOGY

All students were administered the Student Understanding of Science, Scientific Inquiry, and Questioning Survey (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). The Student Understanding, Scientific Inquiry, and Questioning Survey (SSQ) was used to measure pre- and post student views regarding understanding of questioning and inquiry skill application (Appendix A). Student's responses were measured using the Likert scale. Responses were scored as follows: strongly disagree= 1, disagree= 2, agree= 3, and strongly agree= 4. The data were analyzed using modes. The written responses for part one were scored as *informed* or *naive* using the Nature of Science Rubric (Appendix B). The written responses for part two were scored using the Questioning Rubric (Appendix C). Twenty-five percent of the students were then randomly selected and interviewed to clarify their questionnaire written responses using the Nature of Science Interview Questions (Appendix D). The transcripts of students' interviews were compared with the questionnaire data. The focus of the analysis was to see if changes occurred in students' inquiry skills after treatments involving questioning strategies were implemented during the research projects.

Prior to the post- SSQ the students were introduced to questioning strategies including HRASE (History, Relationships, Applications, Speculations, and Explanations) and elaborative interrogation during treatment phase one conducted over an one month period. The HRASE and elaborative interrogation strategies were modeled during topic brainstorming sessions for the students' physics research projects. Teacher Field Notes and video recordings were analyzed to determine the types of questions students' asked in response to discussion from questions I posed during the brainstorming session (Appendix E). The questions were categorized as open, closed, fact-finding, follow-up, and feedback questions. The number of each type of question was tallied and an average for the entire activity was taken.

Students were then introduced to self-questioning models based on cognitive processes and Bloom's Taxonomy over a week long treatment period. They were given an article titled "Asking Effective Questions" showing questioning types and Bloom's Taxonomy (Serrat, 2009). Students were asked to record a list of effective questions in their Physics Research Journals that could be used to lead a follow-up brainstorming session. Data were compiled using Teacher Field Notes, video recordings, and student journals. The Teacher Field Notes Rubric and Physics Research Journal Criteria were used to analyze students' questions.

After the modeling strategies were implemented, students recorded examples of the applied strategies in their Physics Research Journal. Their journals were assessed using the Physics Research Journal Criteria sheet (Appendix F). The Scientific Inquiry and Questioning Interview was conducted with 25% of the subjects who were randomly chosen (Appendix H). This interview was done at the end of the treatment to see if any improvements in questioning and inquiry skill application had been made after the teacher-modeling treatment. Transcripts of the student interviews were analyzed using The Scientific Inquiry Questioning Interview Rubric (Appendix I) and compared with the results of the SSQ. These modeling strategies were implemented over a one treatment period and focused on building students' questioning skills.

After practicing through teacher modeling strategies for one treatment period, students were introduced to the following self-questioning and inquiry strategies: Pre- and Post-lab questions, I-charts (Appendix J), and Questioning the Author (Appendix K). Students practiced using the Pre- and Post-lab strategies before and after each guided-inquiry laboratory activity within the regular physics curriculum. The questions varied depending on the content being covered in class. The I-charts and Questioning the Author strategies were implemented during the students' literature reviews for their physics research projects. Students used the above self-questioning strategies during the second treatment phase which lasted one month.

Within the second treatment phase, the students began using laboratory investigations and their literature reviews to practice generating questions. Pre- and Post-lab activities were used to get students thinking about questions that may be answered by the investigation and to pose extension questions after an investigation (Appendix L). All Pre- and Post-lab questions were recorded in the students' Physics Research Journals and assessed using the Architecture of a Question Rubric scoring system (Appendix M). Questions were scored according to a high/low power designation: yes or no= 1, when, where, which, and who= 2, how and what= 3, and why=4. The data were analyzed using mode. Changes in questioning skills were also compared to the pre- SSQ survey.

The I-Chart and Questioning the Author strategies were used during the students' literature reviews for their specified topic. The I-Chart activity asked students to come up with five research questions for their topic. They were to find information related to the question, record the sources, summarize the information found, and, finally, create a new question. The I-Chart activity was scored using the Architecture of a Question Rubric and the mode was analyzed. Twenty-five percent of the students were then randomly chosen and interviewed to clarify their I-Chart responses using the I-Chart Interview (Appendix N). The Questioning the Author strategy was used to help promote inquiry skills and the ability to form extension questions from what the students read. While reading their publications on their physics research topic, students answered a series of questions about the author's intents in the paper. The students recorded all of their answers in their Physics Research Journals. The data was analyzed using the mode of the following yes or no question: Did the student(s) use inquiry skills while answering the questions? Lastly, the Scientific Inquiry and Questioning Interview was conducted with the same three students in order to compare inquiry and questioning results to the interview from treatment two.

After the third treatment phase, which occurred over a two week period, students were preparing to turn-in their physics research topic proposals. A self-assessment and peer review of the proposal was done before submission. The self-assessment asked students to rate their inquiry and inquiry process skills using the Scientific Inquiry and Questioning Self-Assessment Rubric (Appendix O). The students rated each question with an *exceeds expectations*, *meets expectations*, or *could use some improvement* rating. They then made comments in reference to the question they were asked. A score of three was given to the *exceeds expectations* column, a two for the *meets expectations* column, and a one for the *could use some improvement* column. These scores were tallied using the Likert scale and analyzed using the average for the answers. The results of the self-assessment were then compared with the Scientific Inquiry and Questioning Peer-Review Rubric, which asked the same questions and were scored in the same fashion (Appendix P).

During the fourth phase, which lasted two months, students were encouraged to apply their questioning skills within their data collection during their physics research project. It was during this period that I used Teacher Field Notes and the students' Physic Research Journals for the majority of my data collection. As a reference of the inquiry skills, I wanted students to acquire, I used the Scientific Inquiry and Questioning Rubric for informal observations. I circulated around the room and worked with individual research groups recording all observations of questioning and inquiry skills. In order to analyze the data, I compared my observations with the students SSQ pre-survey scores as a reference to previous questioning and inquiry skills.

Final data collection had students answering the following questions: (1) How have your questioning skills changed throughout your physics research project? (2) How have your inquiry skills changed during your physics research project? Lastly, a final Scientific Inquiry and Questioning Interview was done with the three students interviewed in all other treatments. Their interviews were compared to the previous three interviews to see if changes in questioning and inquiry skills had occurred. The final assessment of questioning and inquiry skills was conducted using the SSQ post-survey.

The results were scored as stated previously and compared to the pre-survey results.

Table 1 and 2 summarize methods and treatment during this study.

Table 1
Data Triangulation Matrix Focus Question

Data Sources	Focus question: How can I improve students' inquiry skills through questioning?	
	Pre-Assessment	Post
Student Understanding of Science, Scientific Inquiry, and Questioning Survey (SSQ, scored with Likert scale)	X	X
Part 1 scores- Nature of Science Rubric (NOS)	X	X
Part 2 scores: Questioning Rubric (QR)	X	X
Nature of Science Interview Questions (NSI, with 25% of students)	X	X

Table 2
Data Triangulation Matrix Focus Sub-Questions

Data Sources	Focus Sub-questions: Effect on inquiry skills?		
	Teacher-modeled questioning: HRASE, elaborative interrogation	Student-generated questioning activities	Application: Student use of questioning in physics project
Video/Voice Recording (VR)	X		
Physics Research Journals (RJ)	X	X	X
Teacher Field Notes (FN)	X	X	X
Scientific Inquiry and Questioning Interview (SIQI)	X	X	X
Pre- and Post-labs (PP)		X	
I-Chart (I)		X	
I-Chart Interview (II)		X	
Questioning the Author (QA)		X	
Architecture of a Question (AQ)		X	
Scientific Inquiry and Questioning Self-Assessment and Peer-Review Rubric (SAPR)			X

DATA AND ANALYSIS

Pre-treatment

The pre-treatment survey SSQ (Appendix A) was used to measure students' views regarding understanding of questioning and inquiry skill application (*N*=14). The data were broken into seven sections: observations and inferences, nature of scientific theories, scientific laws versus theories, social and cultural influences on science, imagination and creativity in scientific investigations, scientific investigations, and questioning.

Student responses were mixed on the pre-treatment SSQ section addressing scientists' observations and inferences. Seventy-one percent of students *agree*d or *strongly agree*d that observations can vary depending on a scientists' prior knowledge, but the same number (71%) thought that scientists' observations of the same event would be the same because observations are facts. All students *agree*d or *strongly agree*d that inferences could be different based on observations.

Application of the Nature of Science Rubric on student written responses revealed that 50% were *naïve* in interpreting observations, meaning they had no response or thought that seeing is believing. One *naïve* student stated, "Everyone looks at things differently so one scientist may see something that the other did not." Responses from the other half of students were *informed* in differentiating observations as statements directly accessed via the senses and that inferences were not. One *informed* student stated, "Scientists' observations may be different because of differences in the environment the experiment is conducted or the method in which it is conducted.

Interpretations of results may be different because of past knowledge and opinions that various individuals hold" (Figure 1).

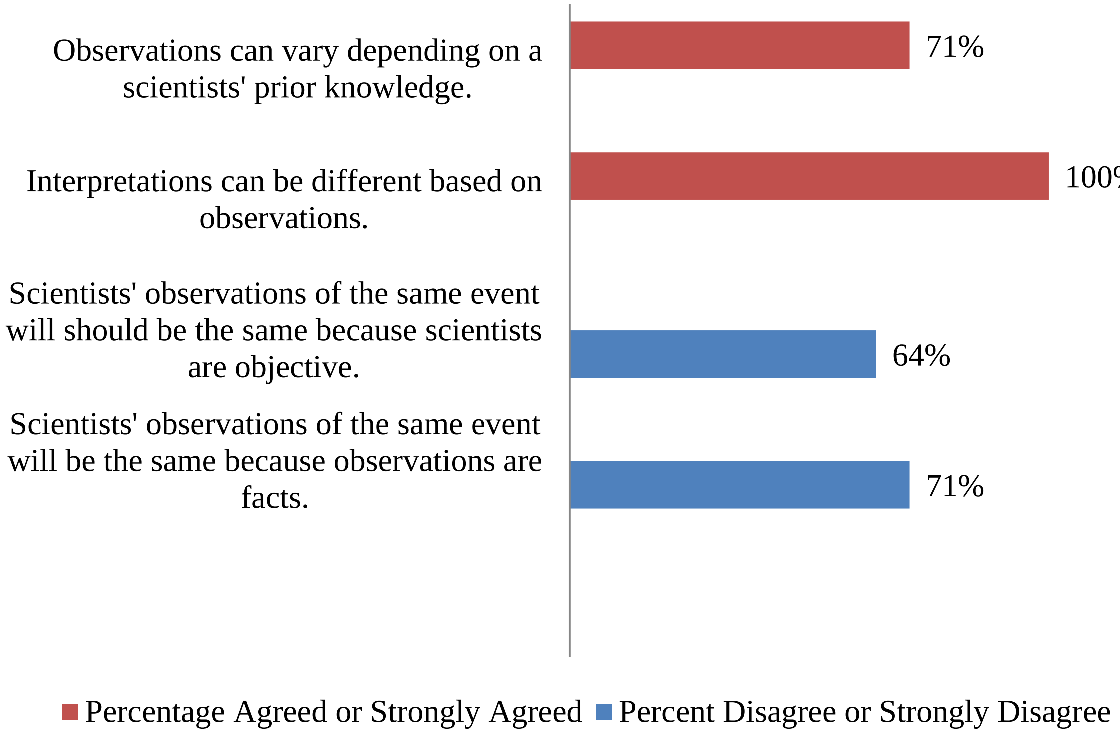


Figure 1. Observation and Inferences Modes, (*N*=14).

Pre-treatment SSQ results regarding nature of scientific theories and the differences between scientific laws and theories sections indicated some maturity in understanding, but also room for improvement. Virtually all students *agree*d (93% to 100% *agree*d and *strongly agree*d to survey statements, and 93% in written responses) that scientific theories are subject to on-going testing and revisions, new evidence, and reinterpretations of observations. One student explained, "Scientists' theories change over time due to new advances in technology. An example of this is the plum pudding model of a neutron being thrown out once microscopes could be used to examine that far." Another student said, "A scientific theory is a hypothesis that has been proven several times or that is widely accepted by the scientific community. A scientific law is an undeniable fact about nature, such as the fact that there is gravity."

However, depending on the phrasing of SSQ statements, some responses showed a misconception of differences between scientific theories and laws; some *naively* thought:

- "Scientific theories could change but usually don't because the theory was developed through experimentation and had already been proven correct."
- "Scientific theories are just a thought on something. Scientific laws are proven and have been proven multiple times so that they are unchangeable."

Furthermore, 86% of students believed scientific laws are theories that have been proven, and a bit more than half of those surveyed (57%) *agree*d that scientific theories explain laws. Another illustration of pre-treatment misconceptions is presented in Figure 2; approximately two-thirds of the students *agree*d, either *strongly agree*d or *agree*d, that scientific laws are subject to change (i.e. response to: "Unlike theories, scientific laws are not subject to change").

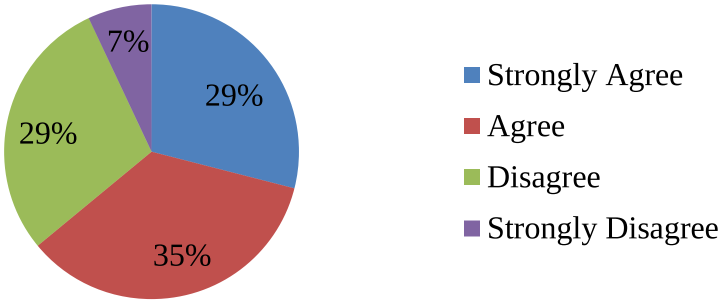


Figure 2. Student Opinions on Scientific Laws, (*N*=14).

Data on social and cultural influences in science indicated a 50-50 split in thinking: half of the students *agree*d (*agree* or *strongly agree*) and half *disagree*d (*disagree* or *strongly disagree*) that scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies and that all cultures conduct scientific research the same way because science is universal and independent of society and culture. Despite the split, 79% of written responses were *informed*, such as one student who said, “Some cultures may not accept findings because it is against their beliefs.” Those who were classified as *naïve* responded with “not sure” or “I think that society and culture does not affect scientific research because their research is majorly based on what happens with the earth or solar system, not the people within it” (Table 3).

Table 3
Pre-Treatment Results of Questions in the Society and Culture Section, (N=14)

Questions	Strongly Agree	Agree	Disagree	Strongly Disagree
Scientific research is not influenced by society and culture because scientists are trained to conduct “pure,” unbiased studies.	14%	36%	36%	14%
Cultural values and expectations determine what science is conducted and accepted	21%	50%	29%	0%
Cultural values and expectations determine how science is conducted and accepted.	0%	57%	36%	7%
All cultures conduct scientific research the same way because science is universal and independent of society and culture.	7%	43%	29%	21%
Explain how society and culture affect or do not affect scientific research.	Naïve 21%	Informed 79%		

Pre-treatment SSQ results in the imagination and creativity in scientific investigations section were similarly divided on whether students felt that a scientists’ work should always be unbiased and objective: 64% of students *disagree*d that scientists use their imagination and creativity when they collect, analyze, and interpret data; but fewer (57%) thought so when the statement was posed as the negative, scientists do not use their imagination and creativity. Written responses were similarly distributed: 57%

gave *naïve* responses, such as thinking the imagination is "dangerous" leading "to twisting facts to suit theories," whereas 43% were *informed* and recognized that "Scientists use their imagination to try and come up with new theories" otherwise "they would never think to question the old scientific ideas that could be untrue."

Data from the scientific investigations section (Figure 3) were comparable to those analyzed in the nature of scientific theories sections. Nearly three-quarters of the students gave *informed* responses on whether scientists follow a single, universal scientific method or use different methods. Again, some discrepancies were observed in student responses when statements were changed or posed differently: twice the number of students *agree*d (*agree*d or *strongly agree*d) to *scientists follow the same step-by-step scientific method* (64%) than *agree*d to *the scientific method should be the only method used* (29%), and 71% *agree*d or *strongly agree*d to *scientists use a variety of methods to produce fruitful results.* No further information was collected from interviews to help decipher these discrepancies.

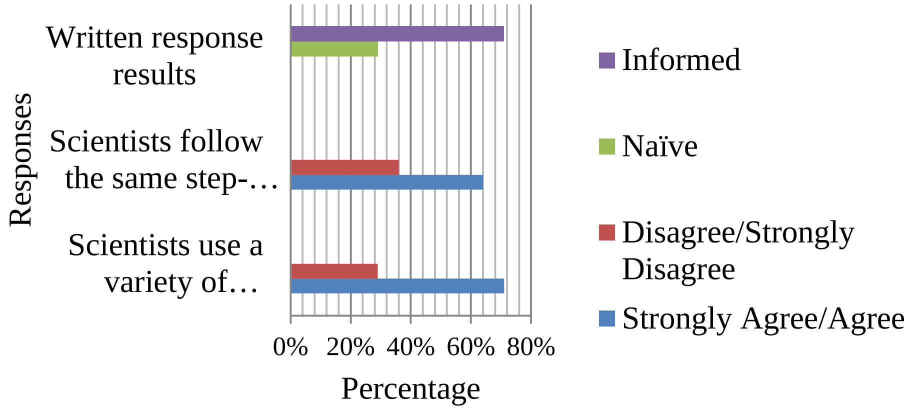


Figure 3. Scientific Investigation Results, (*N*=14).

Results in the questioning portion of the pre-treatment SSQ required students to formulate and classify questions as *low* (answered with a yes or a no) versus *high power* (answered open-ended). Although most students (77%) generated *high power* questions (compared to 23% *low power*), surprisingly none were able to determine what type of questions they had listed. A genuine disconnect was revealed in student thinking about how scientists used questions, 93% had *informed* responses such as “Scientists use questions to clearly state a purpose for their inquiry,” and thinking about how questions are used in inquiry investigations in which only 64% gave *informed* responses. The remaining 36% in the *naïve* category included responses such as “to find something out” or “to find out what people know and what they want to know.”

Teacher-Modeled Questioning Strategies

Upon completion of the pre-treatment survey, Student Understanding of Science, Scientific Inquiry, and Questioning Survey (SSQ) students were exposed to two questioning strategies, HRASE (History, Relationships, Applications, Speculations, and Explanations) and elaborative interrogation. A physics research project brainstorming session was conducted to introduce students to the strategies. Data collected during the round table discussion indicated that 50% of the times when students were asked an *open* type question, one that could be answered with a variety of explanations, the questions that proceeded in succession were *open* type questions. For instance, one student asked, “How can propulsion propel an object?” The other 50% of questions that followed were *fact-finding* questions, which aim at obtaining data and information on a subject. One such question was, “How does surface area and light affect energy absorption?” Similar results were found when students were posed with *closed* type questions, questions that elicit a yes or no answer. For instance, 43% of the time students followed with *open* type questions and 43% of the time with *fact-finding* questions. When a *fact-finding* question was asked to the group, 80% of the questions that came up in the discussion were *fact-finding.* Similar results were found when posed with a *follow-up* question (100% *fact-finding),* which is intended to obtain more data, although only one such question was posed during the discussion. The data also indicates that of all the questions generated during the discussion 38% were *open* type questions, 6% *closed* questions, and 52% were *fact-finding* questions.

When the same questions were analyzed using the *low* and *high power* question categories (Appendix N), 24% of the 29 questions generated were *low power* questions, while 76% of the questions asked were *high power* questions. The data also indicate that when *high power* questions were asked 62% of the questions generated in the subsequent discussion were *high power* questions versus 10% being *low power* questions. According to the data, *low power* questions produced an even split between generating *low* and *high power* questions at 14% each (Table 4).

Table 4
Low versus High Power Questions

Initial Questions		Subsequent Questions			Percentage of serial question types overall
Type	Number	Type	Number	%	
Low	8	Low	4	50%	L→L: 14%
		High	4	50%	L→H: 14%
High	21	Low	3	14%	H→L: 10%
		High	18	86%	H→H 62%

Preceding the brainstorm session, students were given a guide sheet on "Asking Effective Questions." To help them prepare for researching their physics topic, students were asked to make a list of three effective questions they could use in their studies. Of the 32 questions composed by students, 84% were *how* or *what* questions (high power), 13% were *why* questions (high power), and 3% were *when, where, which, who* questions (high power). There were no *yes* or *no* questions generated by students (low power). As an example of the use of *high power* questions, one student stated the following *why* question in her journal, "Why do different conditions affect the rate and temperature of the boiling point of water?" The data indicated a 23% increase, from 77% to 100%, in the use of *high power* questions by students in comparison to the SSQ pre-treatment survey. Figure 4 below shows the results of the analysis.

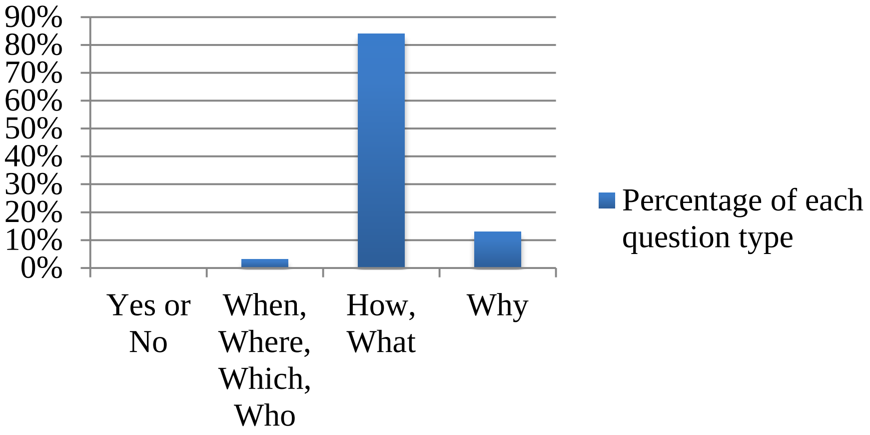


Figure 4. Percentage of High and Low Power Questions, (*N*=32).

<u>Self-Questioning and Inquiry Strategies</u>

After introducing pre- and post- lab questioning strategies, 68% of the questions generated by students were *high power* questions, whereas 32% of the questions written were *low power* questions. For instance, the following *high power* questions were asked during the penny top lab: How would a bigger board affect rotation? What penny arrangement will make it go fastest? Likewise, the following *low power* questions were written prior to the lab: Does the size of the top affect the top? If you add more than one penny can you make [the board] balance by adjusting the pencil?" The change from 77% to 68% is a 9% decrease from the number of *high power* questions and a 9% increase in the number of *low power* questions composed. When the pre- and post- labs were analyzed based on the number of *high* and *low power* questions for pre- versus post- lab questions, the data indicate a 2% increase in the use of *high power* questions during the post-lab versus the pre-lab. However, a 1% decrease was shown when comparing the post-lab *low power* questions to the pre-lab *low power* questions (Table 5).

Table 5
Percentages of High and Low Questions During Pre- and Post- Lab Questions (N=9)

	Pre Lab	Post Lab
% of High	61%	63%
% of Low	39%	38%

The third questioning strategy that was implemented was the Inquiry Chart (I-Chart) strategy. The I-chart data indicated a 22% increase in student generation of *high power* questions when the strategy was used. When students were asked to fill out five research questions on their I-charts, 100% of students listed *high power* questions, which were distributed as 86% *how* and *what*, and 14% *why* questions. However, after students had done literature reviews and were left to generate five new questions on their own without the use of I-charts, only 88% of students wrote *high power* questions. Twelve percent of students regressed into producing *low power* questions, when they were not specifically told to use them.

The final strategy in this treatment was to introduce students to Questioning the Author. This strategy had students choosing an article on energy, work, or power, and organizing and interpreting the data presented by examining the authors' perspective and objectives. Within the students' interpretations (*N*=12), 75% of students used inquiry skills while interpreting the article. For instance, one student said the following while reading an article on solar power, "The author is expressing a positive point of view towards the growth of solar power. The article is objective and there are no [personal] opinions in this article. Though it only looks at the positives of solar energy." The remaining 25% of students did not show inquiry skills for Questioning the Author, because they did not interpret the data and answered the questions as simply as possible as to get through the assignment. For example, one student answered the question *how did the author use this example?* by stating, "He didn't have any examples."

Along with questioning skills, students' inquiry explanations also improved. For instance, between the first and third treatments students' statements became more explanatory. For instance, after being asked *how have you demonstrated scientific inquiry skills so far during this project? Give specific examples* one of the students said, "[When] doing research we look for stuff that will actually help us—not just stupid details that are common sense." However, when asked the same question after the second treatment she stated, "When we go to examine our bottles after they have been freezing for a week, we have to specifically look at the different bottles. Which is broken, which is cracked, which is bulging, and which is fine?" The three other students had similar mindsets when answering the question for a second time.

Self-Assessment and Peer-Review

Data from the Scientific Inquiry and Questioning Self-Assessment and Peer-Review (SAPR) were used to measure student views (*N*= 8 groups) regarding their inquiry and questioning skill application. The data were broken into two sections: ways of knowing in science and processes of science.

During the student self-assessment in the ways of knowing in science section, when given statements regarding connecting ideas with evidence from the inquiry, 75% of students thought they *met expectations* in their paper, whereas 25% thought they *exceeded expectations*. Although they felt confident with connecting evidence, 38% of students thought they could use improvement on documenting changes in their inquiries and changing their focus questions based on what they had learned. The remaining students felt that they *met expectations* (38%) and *exceeded expectations* (25%) in documenting and changing their focus questions based on experimentation. Of the 8 student groups assessed, 13% felt like they *exceeded expectations* on research prior to experimentation, 63% felt they *met expectations*, and 25% of students thought they could have used more research time before beginning their experiments. Overall, 23% of students felt they connected evidence in their inquiry, documented it well, could adjust their focus questions, and did enough research in their inquiry. In addition, 53% of the students felt they *met* these expectations and 25% felt they needed *improvement*. This corresponds to the peer-review data which shows overall 38% of students *exceeded expectations,* 41% *met expectations,* and 22% needed *improvement.* Figure 5 below illustrates the data.

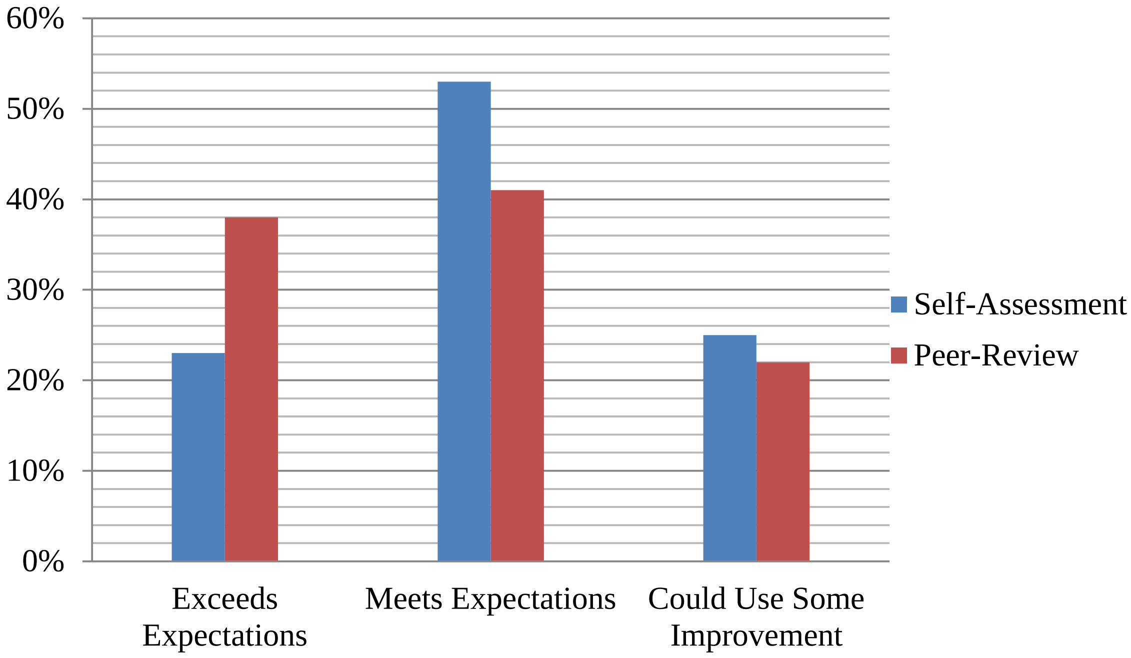


Figure 5. Percentages for Student Self-Assessment and Peer-Reviews, (*n*=8).

Results from SAPR for the processes of science section show that most student groups thought they *exceeded* expectations (38%) or *met expectations* (50%) when it came to making detailed observations and communicating their processes and ideas. Only one student group out of eight (13%) indicated that they needed *improvement* on observations and communicating. Student groups responded similarly on whether they had used the best measuring tools for their inquiry and if they thought of new questions as they worked through their data collection. Two groups (25%) felt as if they *exceeded expectations*, and the remaining two (25%) of students felt like they needed *improvement* on measurement tools and creating new questions.

Comparable to observations on the increased use of *high power* questions in the Questioning the Author section above, SAPR results showed that all groups felt they had *met expectations* (75%) or *exceeded expectations* (25%) in identifying a question as testable or effective (i.e. *How did you know that your question that guided the inquiry was testable?)*

Fifty percent of students, the highest percentage in this section, indicated they *exceeded expectations* in explaining why their plan for inquiry was the best one for them. Overall, 33% of students *exceeded expectations* in this section, 48% *met expectations,* and 19% of student felt they needed to *improve* in these areas. Again, these results are close to the results indicated in the peer-review assessment: 39% *exceeded expectations,* 50% *met expectations,* and 11% needed *improvement* in the indicated areas. The results are shown below in Figure 6.

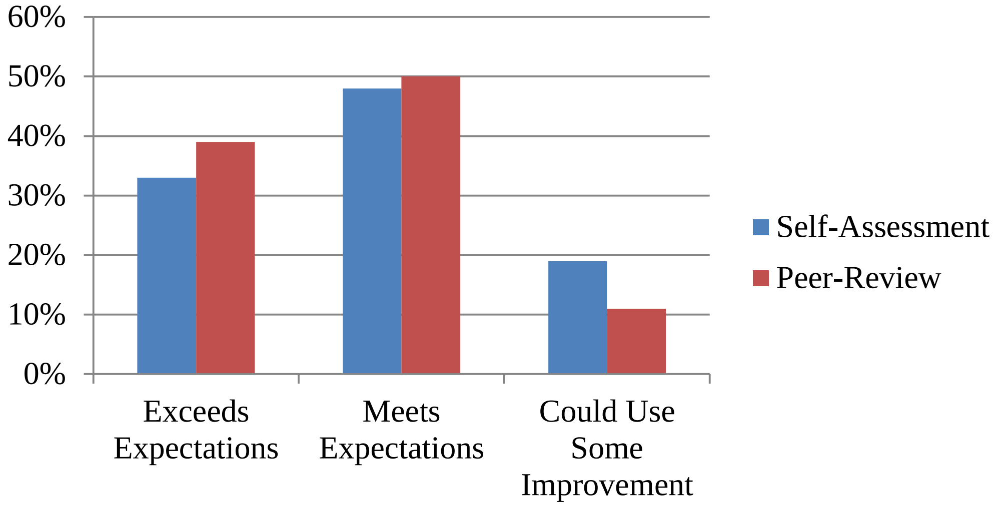


Figure 6. Self-Assessment and Peer-Review Percentages Processes of Science Section, (*n*=10 Self-Assessment, *n*=13 Peer-Review).

Student Inquiry Investigation

Data during the fourth treatment phase was collected using Teacher Field Notes. As I mingled with research groups I observed the following trends:

(1) Students were using *high power* questions. When asked to explain their reasoning behind the questions, students would indicate that the question they wrote was

high power, an inquiry question, or an effective question. This is a dramatic change from when students took the pre-SSQ survey, in which 0% of the students could identify the type of questions they were using. I also observed students mocking each others' questions when someone used a yes or no question in the research setting saying "that's not an effective question. I'm not going to answer that."

(2) Students were adjusting their previous questions to encompass variables. For instance, after testing the distribution of pennies on their penny top board I overheard one group say, "What would a bigger scale yield with this experiment?" They went on to discuss how they could use a merry-go-round, Velcro, and Velcro suits to test their new question. A similar conversation occurred after a group accidentally launched a cork to the ceiling after they added the variables of boiling and pressure to their flask. They were troubleshooting how they were going to keep the increase in pressure as a variable without the cork flying off again.

(3) Students were having a difficult time analyzing data that was qualitative. While conversing with the groups, I told them they would need to record their observations by using their five senses as their guide. After several weeks of having to interpret these observations, students must have grasped it because their understanding of observations and interpretations as informed individuals increased by 29% from pre-SSQ to the post-SSQ.

(4) Lastly, students negotiated project challenges by changing or revising their methodology, focus questions, and literature reviews. I noticed that a lot of

> students were making changes after a few failed test runs, because they were unable to get their devices working or could not come up with the supplies to complete their experiment. For instance, one student had to resort to talking to a Montana Tech physics professor because she did not have access to the equipment she needed. After working under his guidance, she had to completely switch her focus because her use of continuous sound and measuring it was not going to work with the equipment she had available to her. Overall, I saw students using questions, caring about precision with measurements, students recording and analyzing data, and troubleshooting unexpected challenges in their experiments.

Comparable data was shown when students were asked *How have your questioning skills changed throughout your physics research project?* Of the 11 students surveyed, 100% of students felt as if their questioning skills had improved. For instance, one student stated, “My questioning skills have changed by the way I think before I ask a question. An example of this is asking more in-depth questions that have legitimate reasoning, not just surface questions.” Students had similar feelings (82%) when asked *How have your inquiry skills changed throughout your physics research project?* For instance, one student said the following about his inquiry skills, “I have the ability to see patterns in data. I can [now] do more research in a small amount of time.” A second student stated this about his inquiry skills, “My inquiry skills have changed for the better. I ask more in-depth questions now. An example of this is, “What would happen if gas is pressurized and then inserted into a pipe and lit on fire?’”

Post-Treatment

A final Student Understanding of Science, Scientific Inquiry, and Questioning Survey (SSQ) was conducted following treatments one through four. In the observations and inferences section, post-treatment data indicated an increase of 15%, from 71% to 86%, in students who *strongly agree*d or *agree*d that scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations. This corresponds with the 29% increase in *informed* responses when students were asked why they think scientists' observations and interpretation are the same or different. However, students' opinions did not change in regards to thinking scientists will always think the same thing because they are objective (64% *disagree/strongly disagree*) and they still believe (100%) that scientists may make different interpretations based on the same observations.

In the nature of scientific theories section students increased understanding in two areas. When asked if scientific theories may be completely replaced by new theories in the light of new evidence, students increased the number of *agree* and *strongly agree* responses by 7%. A 7% increase was also shown when students were asked if scientific theories based on accurate experimentation will change. Students increased their rate of *disagree* and *strongly disagree* responses from 79% to 86%. However, student responses decreased by 14% on their understanding that scientific theories can be changed because scientists often reinterpret existing observations.

The scientific laws vs. theories section of the post-treatment SSQ demonstrated several drastic changes in opinions among students. For instance, when the survey stated *scientific theories exist in the natural world and are all uncovered through scientific* *investigations,* 86% of students *agreed* or *strongly agreed* with the statement. This is a 57% increase in the *agreed* or *strongly agreed* category after the treatment phases. Unfortunately, the post-treatment SSQ data also indicated two decreases in understanding compared to from the pre-survey. Students understanding of the statement *unlike theories, scientific laws are not subject to change* decreased by 15%, in that 79% of students *agree*d or *strongly agree*d with the statement after the treatments. Similarly, 86% agreed (compared to 100%) when asked if *scientific laws were theories that had been proven*. However, when students were asked to explain the difference between theories and scientific laws there was a 22% increase in the number of *informed* students. Overall, the scientific laws and theory category gained a 50% increase in student understanding.

In the social and cultural influence on science category, students increased their understanding by 14%, from 57% *agreeing* or *strongly agreeing* to 71% post-treatment, when presented with the statement that cultural values and expectations determine how science is conducted and accepted. Students understanding also gained 21%, from 50% *disagreeing* or *strongly disagreeing* to 71% post-treatment, in determining that not all cultures conduct scientific research the same way. Conversely, despite the increased understanding in the above categories, the *informed* student percentages decreased by 15%, from 79% to 64% post-treatment.

The imagination and creativity in scientific investigations categories showed decreases in understanding for three subcategories. A loss of 7% understanding was observed regarding statements *scientists do not use their imaginations and creativity because these conflict with their logical reasoning* and *scientists do not use their* *imagination and creativity because these can interfere with objectivity*. The data indicated slightly higher loss (-15%) when students were asked to explain why scientists use or do not use imagination and creativity. Although the students think scientists don't use imagination and creativity because of conflict with reasoning and objectivity, student understanding regressed by 14% in the more *agree*d and *strongly agree*d that scientists use it to analyze and interpret data.

The final category, inquiry showed an overall increase in understanding by 8%. Students improved in three subcategories and decreased understanding in two categories. A 7% increase was observed in student *disagreement* towards scientists following the same scientific method and the method giving true and accurate results. Student understanding increased by 15% concerning development of scientific knowledge. However, small losses in understanding (7%) were observed for responses to the statement that scientists use a variety of methods to produce fruitful results. The number of *informed* students decreased by 14% when asked to explain whether scientists follow a single, universal scientific method or use different methods.

The data from the SSQ section on questioning indicated a 5% increase, 77% pre- to 82% post-treatment, in student writing of *high power* questions. A substantial increase of 79%, from 0% to 79%, was demonstrated in students' abilities to determine the type of questions they listed. Results of the question *how are questions used in inquiry investigations* also showed a 36% increase, from 64% to 100%, in the number of *informed* students. The only question that did not show an increase (-7% *informed*) was when students were asked *how do scientists use questions*?

Upon further analysis, students showed an increase in understanding in the following categories: observation and inferences, scientific laws vs. theories, social and cultural influence on science, scientific investigations, and questioning. A decrease in understanding occurred in the imagination and creativity in scientific investigations category, and no change in the nature of scientific theories category (Figure 7).

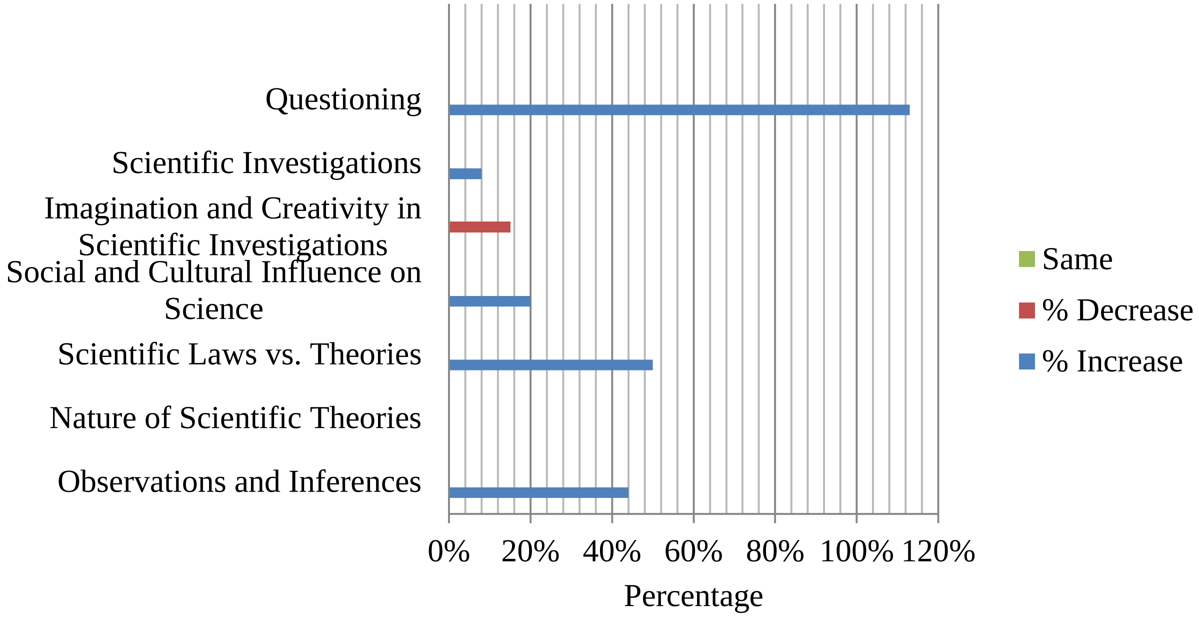


Figure 7. Cumulative Percent Change in Students' Inquiry and Questioning Skills, (*N*=14).

INTERPRETATION AND CONCLUSION

The project focused on the effectiveness of questioning strategies on students' inquiry skills during a physics research project. Evaluation of the data collected indicated the use of questioning strategies, both teacher-modeled and student applied models, assisted students in developing inquiry skills while conducting their inquiry investigations. Most notably, the final survey showed an increase in science understanding and use in five of the seven assessed categories on inquiry and questioning.

Prior to the treatments, many of my students couldn't define the word inquiry and none of the students were able to tell me what kind of questions they had composed. The HRASE and elaborative interrogation strategies, along with provided sheet on the Asking

Effective Questions, caused students to consider the type of questions they were using in science and how the questions should be used. The data presented above indicated that students are more likely to use *open* type questions or *high power* questions when they are exposed to those types of questions. This result mirrors studies done by Jarrett (1997) and Hall & Sampson (2009) who say exposing students to questioning strategies helps students apply the skills to build thinking and explanations in science. However, by my experience in this research, students asked *open* type or *high power* questions only if they were continually reminded to do so, at least at the beginning of learning the strategies. For instance, when students were told to write three questions at the beginning of the lab and three after, there was a 22% decrease in the use of *high power* questions without the reminder. This illustrated the importance of practicing the strategies until students had mastered the skill.

Although students were generally engaged in the physics inquiry labs done in class, I noticed that students produced more effective science questions after they'd had some experience with what they were studying. This was observed after examining pre-lab and post-lab questions and students' self-assessment and peer reviews. After students conducted the penny top lab they were coming up with more *high power* questions and applying them to real world situations. This observation supported the premise that students need practice with questioning and inquiry skills, and that with practice, students build skills to become more explanatory during investigations as indicated by the data after treatment two.

Immersing students in the questioning and inquiry strategies really does help students become better scientists. When students met challenges in their research investigations, they looked for guidance within the tools I gave them at the start of their investigations. For instance, several students had to revamp their projects because they lacked access to supplies or they obtained minimal results in their initial tests. These students used the questioning strategies, which I had taught in order to develop new questions and they used the I-chart to do further research for their projects. In my experience, students don't like gray areas and will seek answers with what is familiar and accessible. If students are given a tool, they will return to what they understand and are most comfortable with to meet a challenge.

VALUE

Every year I've taught science I've worked to build a solid program. One of my current goals is to start a science fair at my school. However, I would feel more comfortable launching the effort after a small trial run and more practice with teaching and building my students' inquiry and questioning skills. The reason for selecting my focus topic, using questioning strategies to improve inquiry skills, was to help me become a better questioner and helper in the inquiry investigation process, in hopes that I can pass these skills onto students during a school-wide science fair. This project has had multiple effects; first, it has forced me to be accountable for the types of questions I utilize with students on a daily basis. It has also encouraged me to be a more hands-off teacher and to let my students take the reins in the inquiry process.

Secondly, the literature review has overwhelmed me with new approaches to teaching questioning and building inquiry skills. I'd never heard of the Questioning the Author and I-Charts approaches before conducting this research. I found the strategies to be very beneficial for encouraging data interpretation and effective questioning in the classroom. These are skills I will implement in all of my classes from this point forward. These strategies have also piqued my interest on investigating the effectiveness of other strategies for building inquiry and questioning skills.

The third change I've seen from this project is that teaching questioning and inquiry skills is important and necessary. Most students don't come into my classroom with science based minds. They are not careful with observations or measurements, and rarely ask extension questions after they have completed a laboratory investigation. With these factors in mind, I now am even more adamant about teaching appropriate questioning skills, about exposing students to inquiry investigations as much as possible, and about training them how to think like a scientist. Over the course of the physics research projects, I saw great strides in my senior's research skills. I am firmly convinced that these strides were due, in part, to students mastering new questioning skills and applying them to the inquiry process.

Lastly, I'm proud to say that my skill as a questioner has changed. Reflecting on the types of questions, I now often catch myself and change the questions mid-sentence because I have not asked a *high power* question. I even say outloud, "That's not a good question, let me rephrase that." In addition, I find myself talking to my students more when they are involved in their own research projects. I've become more in tune with their research, with their learning styles and interests, and with them as individuals. After watching my students' progress through these projects, I am even more encouraged to start a science fair and get students involved in more individual inquiry investigations on an annual basis.

REFERENCES CITED

BSCS. (2011). Inquiry. Retrieved September 27, 2011, from http://www.bscs.org/curriculumdevelopment/features/inquiry.html

Chin, C., & Osborne, J. (2008). Students' Questions: A Potential Resource for Teaching and Learning Science. *Studies in Science Education*. *44*(1), 1-39.

Daily, Quinn (2010). *Explicit Nature of Science Instruction and the 5E Learning Cycle: A Gateway to Scientific Literacy.* Unpublished professional paper, Montana State University-Bozeman.

Elder, L., & Paul, R. (1998). The role of Socratic questioning in thinking, teaching, and.. *Clearing House*, *71*(5), 297. Retrieved from Academic Search Premier database.

Good, T., & Brophy, J. (1997). Looking in Classrooms. New York: Longman.

Hall, C. B., & Sampson, V. (2009). Inquiry, Argumentation, and the Phases of the Moon: Helping Students Learn Important Concepts and Practices. *Science Scope*. *32*(8), 16-21.

Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. (2000). Retrieved September 27, 2011, from http://www.nap.edu/openbook.php?record_id=9596&page=1

Jarrett, D. (1997). Inquiry Strategies for Science and Mathematics Learning: It's Just Good Teaching. *Northwest Regional Education Laboratory.*

Kaberman, Z., & Dori, Y. J. (2009). Question Posing, Inquiry, and Modeling Skills of Chemistry Students in the Case-Based Computerized Laboratory Environment. *International Journal of Science and Mathematics Education*. *7*(3), 597-625.

Latham, A. (1997). Asking students the right questions. *Educational Leadership*, *54*(6), 84. Retrieved from Academic Search Premier database.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002).Views of Nature of Science Questionnaire (VNOS): Toward Valid Meaningful Assessment of Learners' Conceptions of Nature of Science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Lin, H.-s., Hong, Z.-R., & Cheng, Y.-Y. (2009). The Interplay of the Classroom Learning Environment and Inquiry-Based Activities. *International Journal of Science Education*. *31*(8), 1013-1024.

Lucas, D., Broderick, N., Lehrer, R., & Bohanan, R. (2005). Making the Grounds of Scientific Inquiry Visible in the Classroom. *Science Scope*. *29*(3), 39-42.

Marchbad-Ad, G., & Sokolove, P. (2000). Can undergraduate biology students learn to ask higher level questions? *Journal of Research in Science Teaching*, *37,* 854-870.

Menke, D.J., and M. Pressley (1994). Elaborative Interrogation: Using “Why” Questions to Enhance the Learning from Text. *Journal of Reading*. *37*(8), 642-645.

Montana Public School Enrollment Data (2010). Retrieved September 27, 2011, from http://opi.mt.gov/pdf/Measurement/EnrollBook2011.pdf

Ogle, D. (2009). Creating Contexts for Inquiry: From KWL to PRC2. *Knowledge Quest*. *38*(1), 56-61.

Osborne, J., Erduran, S., & Simon, S. (2004). *Ideas, Evidence & Argument in Science.* London: King’s College.

Pieczura, M. E. (2009). Dare to Disagree, as Scientists. *Science and Children*. *47*(3), 24-27.

Polacek, K. M., & Keeling, E. L. (2005). Easy Ways to Promote Inquiry in a Laboratory Course: The Power of Student Questions. *Journal of College Science Teaching*. *35*(1), 52.

U. S. Census Bureau. (2000). *Census 2000 Summary*. Retrieved March 14, 2010, from http://en.wikipedia.org/wiki/Deer_Lodge_County,_Montana

Wood, F., M. Pressley, and P.H. Winne (1990). Elaborative Interrogation Effects on Children’s Learning of Factual content. *Journal of Educational Psychology*. *82*, 741-748.

APPENDICES

APPENDIX A

STUDENT UNDERSTANDING OF SCIENCE, SCIENTIFIC INQUIRY, AND QUESTIONING SURVEY

Part I: Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement.

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

1. Observations and Inferences				
A. Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	A	SA
B. Scientists' observations of the same event will be the same because scientists are objective.	SD	D	A	SA
C. Scientists' observations of the same event will be the same because observations are facts.	SD	D	A	SA
D. Scientists may make different interpretations based on the same observations.	SD	D	A	SA
With examples, explain why you think scientists' observations and interpretations are the same OR different.				

*Adapted from Leberman et. al. 2002

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

2. Nature of Scientific Theories				
A. Scientific theories are subject to on-going testing and revision.	SD	D	A	SA
B. Scientific theories may be completely replaced by new theories in light of new evidence.	SD	D	A	SA
C. Scientific theories may be changed because scientists reinterpret existing observations.	SD	D	A	SA
D. Scientific theories based on accurate experimentation will not be changed.	SD	D	A	SA
With examples, explain why you think scientific theories change OR do not change over time.				

*Adapted from Leberman et. al. 2002

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

3. Scientific Laws vs. Theories				
A. Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	A	SA
B. Unlike theories, scientific laws are not subject to change.	SD	D	A	SA
C. Scientific laws are theories that have been proven.	SD	D	A	SA
D. Scientific theories explain scientific laws.	SD	D	A	SA

With examples, explain the difference between scientific theories and scientific laws.

*Adapted from Leberman et. al. 2002

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

4. Social and Cultural Influence on Science				
A. Scientific research is not influenced by society and culture because scientists are trained to conduct "pure," unbiased studies.	SD	D	A	SA
B. Cultural values and expectations determine what science is conducted and accepted.	SD	D	A	SA
C. Cultural values and expectations determine how science is conducted and accepted.	SD	D	A	SA
D. All cultures conduct scientific research the same way because science is universal and independent of society and culture.	SD	D	A	SA
With examples, explain how society and culture affect OR do not affect scientific research.				

*Adapted from Leberman et. al. 2002

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

5. Imagination and Creativity in Scientific Investigations				
A. Scientists use their imagination and creativity when they collect data.	SD	D	A	SA
B. Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	A	SA
C. Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.	SD	D	A	SA
D. Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	SD	D	A	SA
With examples, explain why scientists use OR do not use imagination and creativity.				

*Adapted from Leberman et. al. 2002

SD= Strongly Disagree
D= Disagree More Than Agree
A= Agree More Than Disagree
SA= Strongly Agree

6. Scientific Investigations				
A. Scientists use a variety of methods to produce fruitful results.	SD	D	A	SA
B. Scientists follow the same step-by-step scientific method.	SD	D	A	SA
C. When scientists use the scientific method correctly, their results are true and accurate.	SD	D	A	SA
D. Experiments are not the only means used in the development of scientific knowledge.	SD	D	A	SA

With examples, explain whether scientists follow a single, universal scientific method OR use different methods.

*Adapted from Leberman et. al. 2002

Part II: Questioning

A. List 5 research questions geared toward your physics research project topic.

B. What type of questions are the questions you listed above?

C. How do scientists use questions?

D. How are questions used in inquiry investigations?

APPENDIX B

NATURE OF SCIENCE RUBRIC

Nature of Science Criteria	INFORMED	NAÏVE
Observation versus Inference	Observations are descriptive statements about natural phenomena that are directly accessible to the senses. Inferences are statements about phenomena that are not directly accessible to the senses.	No response or "seeing is believing"
Nature of Scientific Theories	Scientific theories can change if new observations, evidence, or accurate experimentation has proven a change should occur.	It is unchanging.
Scientific Laws vs. Theories	A scientific theory is an inferred explanation for observable phenomena that is based on multiple lines of evidence. A scientific law usually refers to a generalization about data and is a compact way of describing what we'd expect to happen in a particular situation. Scientific laws may have exceptions, and like other scientific knowledge, may be modified or rejected based on new evidence and perspectives.	A scientific theory is a guess or hunch. A scientific law is a rule that must be abided or something that can be relied upon to occur in a particular situation.
Social and Cultural Influence on Science	Scientific knowledge is subjective. Scientists' previous knowledge, training, experiences, and expectations actually influence their works and affect the problems scientists decide to investigate, how they conduct their investigations, and how they make sense of and interpret their observations.	Different conclusions are due to different evidence. Scientists are not influenced by any outside factors.
Imagination and Creativity in Scientific Investigations	Scientific knowledge involves human imagination and creativity. Science involves designing of investigations, analyzing the data and explaining conclusions incorporating a great deal of creativity.	Imagination is not real. Imagination and creativity are not used in science.
Scientific Investigations	The process of science is exciting, complex, and unpredictable. It involves many different people, engaged in many different activities, in many different orders. The Scientific Method represents how scientists usually write up the results of their studies (and how a few investigations are actually done), but it is a grossly oversimplified representation of how scientists generally build knowledge.	There is a single Scientific Method that all scientists follow during scientific investigations.

*Adapted from Daily, 2010.

APPENDIX C

QUESTIONING RUBRIC

A. Score questions according to the Architecture of a Question Rubric.

B. Score questions with a yes (2) or no (1). *Yes* indicates they were able to identify the type of question. *No* indicates they were not able to identify the type of questions.

Types of questions:

-Open Questions

-Closed Questions

-Fact-finding Questions

-Follow-up Questions

-Feedback Questions

C. Scientists use questions to begin the early stages of an investigation. Questions often lead to further observations, investigations, sharing ideas and data, and learning about what's already been discovered.

D. Similar answer to C is appropriate. Students should begin to explain how questions drive the scientific process.

APPENDIX D

NATURE OF SCIENCE INTERVIEW QUESTIONS

Prompt: In this interview we will be reviewing your written responses to the Student Understanding of Science, Scientific Inquiry, and Questioning Survey. I will be recording this interview so I will be able to correctly understand your answers to the written questions I asked you on the survey. For each question, please re-read the question and your written answer aloud then explain your answers using as many details as you can.

End Interview: Is there anything else you want me to know about the survey topic(s)?

APPENDIX E

TEACHER FIELD NOTES RUBRIC FOR BRAINSTORMING ACTIVITY

1) List types of questions you asked.

2) What types of questions did students ask as a result of your questions?

APPENDIX F

PHYSICS RESEARCH JOURNAL CRITERIA

The purpose:

- -to encourage you to think further on the topic and research you've done.
- -to elaborate on and practice the skills of scientific inquiry.
- -to allow an avenue of discussion and communication of ideas between student and teacher.

Journal Criteria:

1. Record observations and questions that arise throughout the inquiry.
2. Reflect on collected data.
3. Record any "a huh" moments that arise throughout the inquiry.
4. Record data in tables and graphs with appropriate labels.
5. Keep a record of literature reviews.

Journal Guidelines:

1. All entries should focus on your physics research project.
2. All entries will be either printed or written in script, as long as they are neat and legible.
3. No doodling in the journal. Diagrams and pictures associated with the topic are acceptable.
4. The number of journal entries will depend on the number of class periods during the week. If there are two block classes, two will be required. If there are three block classes, three will be required.
5. Time to write in journals:
    - -Assigned research time.
    - -When you have finished assigned work in class.
    - -As homework.
    - -After any research work.

APPENDIX G

SCIENTIFIC INQUIRY AND QUESTIONING INTERVIEW

1. Give an example of a question you’ve been focusing on during this portion of your research.

2. What type of question is it?

3. What events/happenings caused you to initially come up with the question?

4. How has this question guided/influenced your work during this project?

5. What new questions have been formulated from the data you’ve recently collected?

6. How have you demonstrated scientific inquiry skills so far during this project? Give specific examples.

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

APPENDIX H

THE SCIENTIFIC INQUIRY QUESTIONING INTERVIEW RUBRIC

1. Score questions according to the architecture of a question rubric.

2. Score question with a *yes* (2) or *no* (1). *Yes* indicates they were able to identify the type of question. *No* indicates they were not able to identify the type of question.

    Appropriate responses:

        -Inquiry
        -Research
        -Testable
        -Effective (how, why, what)

3. If they were able to describe the events in terms of inquiry research (action---reaction) they earn 2 points. If not, they earn 1 point.

4. If they can describe they learned, changed, or observed as part of their research, they earn 2 points. If not, they earn 1 point.

5. Score questions according to the architecture of a question rubric.

6. If they describe procedures, observations, tests, and/or questions they earn 2 points. If not, they earn 1 point.

APPENDIX I

I-CHART

Topic: ________________________________

Name: ________________________________

	Research Question #1	Research Question #2	Research Question #3	Research Question #4	Research Question #5
Source 1					
Source 2					
Source 3					
Other Interesting Facts					
Summary					
New Questions					

APPENDIX J

QUESTIONING THE AUTHOR

Directions: As you read each publication focused on your physics research topic, break the publication into sections. Address the following questions in each section. A minimum of two sections should be used.

1. What was the author trying to say in this section?

2. What point of view is the author expressing in the paper?

3. If the author provides examples within their research that focuses on your research topic, why did the author use this example?

4. How would you explain these examples to a peer not studying your topic?

5. What else could the author have said to make the point more clear?

6. What visual information or diagrams enhanced or could enhance the ideas?

APPENDIX K

DISCOVERY LAB (PENNY TOPS LAB)

1. Pose two questions prior to the investigation.

2. State the purpose of the experiment.

3. Describe the procedures of the experiment.

4. Graphically (quantitative) illustrate the collected data or describe observations (qualitative).

5. Analysis of data.

6. Pose two extension questions after the investigation.

7. Conclusion

APPENDIX L

REBOUND HEIGHT

An object’s momentum is the product of its mass and velocity.

1. Drop a large rubber ball from about 15 cm above a table.

2. Measure and record the ball’s rebound height.

3. Repeat steps 1-2 with a small rubber ball.

4. Hold the small rubber ball on top of, and in contact with, the large rubber ball.

5. Release the two rubber balls from the same height, so that they fall together.

6. Measure the rebound heights of both rubber balls.

	Rebound Height
Large Ball	
Small Ball	
Both Balls	

Analyze and Conclude

7. Describe the rebound height of each rubber ball dropped by itself.

8. Compare and contrast the rebound heights from number 7 with those from number 6.

9. Explain your observations.

10. Pose two extension questions.

APPENDIX M

INTRODUCTION TO ENERGY MODEL PHET LAB

In this lab, you will analyze energy transfer between gravitational potential energy, kinetic energy, and dissipated energy (thermal energy in this sim) as a skate boarder rides inside a half-pipe.

Pre-Lab

Pose three questions you hope to discover during this investigation

1.

2.

3.

Part A – No Friction

1. Open the Energy Skate Park Basics PhET simulation as instructed in class.
2. Check the Bar Graph option on the right of the simulation.
3. Click on the skateboarder, place him on the track at the top of the half-pipe, and let him go. Click the slow-motion option at the bottom to make things easier to follow.
4. As the skateboarder rides back and forth…
   a. Describe how the potential energy changes.

   b. Describe how the kinetic energy changes.

   c. Describe how the total energy changes.

5. Now click the Pie Chart option on the right of the simulation and observe the pie chart as the skateboarder rides back and forth.
   a. What does the total size of the pie represent?

6. Now check the Grid option on the right of the simulation. As the height of the skateboarder changes…
   a. Describe how the potential energy changes.

   b. Describe how the kinetic energy changes.

7. Now check the Speed option on the right of the simulation and observe the speedometer. As the speed changes…
   a. Describe how the potential energy changes.

   b. Describe how the kinetic energy changes.

Part B – Friction

1. Now click the Friction tab at the top of the simulation.
2. Check the bar graph option and pie chart option on the right of the simulation.
3. Turn friction on and set the slider bar for the friction amount at roughly 25%.
4. Click the slow-motion option at the bottom to make things easier to follow.
5. Place the skateboarder on the track at the top of the half-pipe and let him go.
6. As the skateboarder rides back and forth…
   a. Describe how the potential energy changes.

   b. Describe how the kinetic energy changes.

   c. Describe how the thermal energy (dissipated energy) changes.

   d. Describe how the total energy changes.

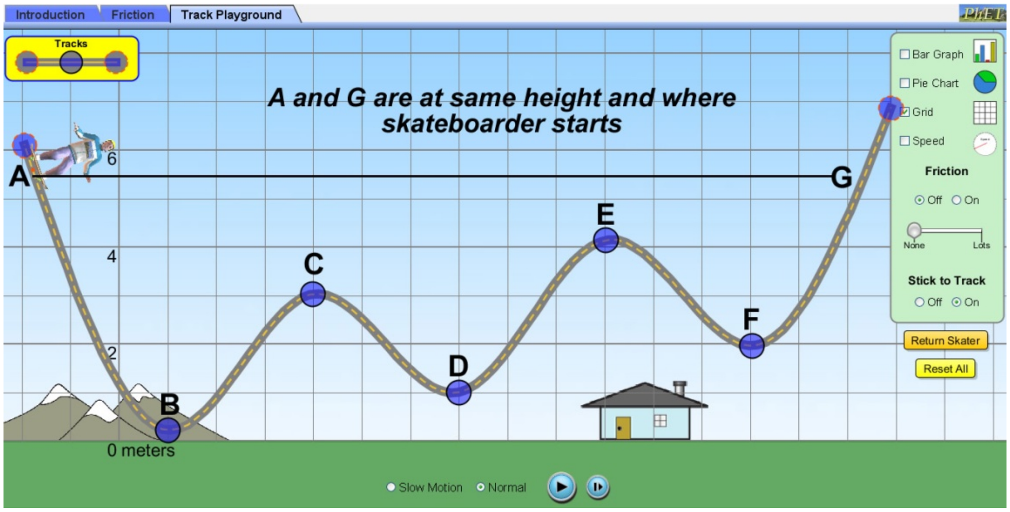
7. After the skateboarder comes to a stop, turn on the Grid and Speed options on the right of the simulation.
8. Place the skateboarder on the track at the top of the half-pipe and let him go again.
9. As the skateboarder rides back and forth…
   a. Describe how the maximum velocity changes.

   b. Describe how the maximum height changes.

Part C – Track Playground Ranking Tasks (friction turned off)

Do the ranking tasks below assuming no friction. Use the Track Playground tab for help.

.



A and G are at same height and where skateboarder starts

☑ Grid
☐ Speed
Friction ● Off ○ On
None — Lots
Stick to Track ○ Off ● On
○ Slow Motion ● Normal

1. Rank the skateboarder positions A – G above in order of greatest potential energy to least potential energy. Ties are possible.

   ___ ___ ___ ___ ___ ___ ___

2. Rank the skateboarder positions A – G above in order of greatest kinetic energy to least kinetic energy. Ties are possible.

   ___ ___ ___ ___ ___ ___ ___

Post-Lab

Come up with three additional testable questions you could use with this simulation.

1)

2)

3)

APPENDIX N

ARCHITECTURE OF A QUESTION RUBRIC

	Type of Question	**Score**
Low Power	Yes or No Questions	1
↕	When, Where, Which, Who	2
	How, What	3
High Power	Why	4

APPENDIX O

I-CHART INTERVIEW

Prompt: In this interview we will be reviewing your research questions from the I-Chart activity. I will be recording this interview so I will be able to correctly understand why you chose each of the research questions.

1. Tell me about your research questions.
2. What type of questions are the five questions you chose?
3. What kind of information did you expect to get from these questions?
4. Tell me about the new questions you posed.
5. Is there anything else you’d like me to know?

APPENDIX P

THE SCIENTIFIC INQUIRY AND QUESTIONING SELF-ASSESSMENT RUBRIC

	Exceeds expectations	**Meets expectations**	**Could use some improvement**	**Comments (must be filled out by the reviewer)**
Ways of knowing in Science				
Can you connect all of your ideas with evidence found in the inquiry?				
Did you change your mind about the inquiry? Can you document how this happened?				
Would you make any changes in your focus question based on what you know now?				
How much research did you do to find out about your topic?				
Processes of science				
Are your observations as detailed as you can make them?				
Did you use the best tools to make measurements in the inquiry? Did you do research to find other tools that measure the same quantities? Could your data be more precise when you use these other tools?				
How did you know that your question that guided the inquiry was testable?				
Did you think of other questions as you progressed through the inquiry?				
Can you explain why your plan for inquiry was the best one for you?				
Could you communicate your processes and ideas differently?				

APPENDIX Q

THE SCIENTIFIC INQUIRY AND QUESTIONING PEER-REVIEW RUBRIC

	Exceeds expectations	**Meets expectations**	**Could use some improvement**	**Comments (must be filled out by the reviewer)**
Ways of knowing in Science				
Are all ideas backed up with evidence from the inquiry?				
If the group/individual changed their way of thinking about the inquiry, could they explain why? Was there a point in the inquiry where the group got stuck? How did they get over that barrier?				
Did the group/individual go back to improve their focus question? Could the group explain or document how their focus changed as they learned more about the topic and collected data?				
Did the group/individual do additional literature reviews during experimentation when new information was discovered? Is there evidence?				
Processes of science				
Did the group/individual record observations that everyone, even if they weren't involved in the inquiry, could understand?				
Did the group/individual think about other ways to measure in their inquiry?				
Did the group/individual try to predict what might happen in their inquiry?				
Did the group/individual begin with a general question that was testable?				
As the group/individual went through the inquiry did more questions come out of the study?				

Did the group/individual have a plan for their inquiry that made sense?				
Did the group/individual follow the plan? If not, can they explain why they didn't follow the plan?				
Did the group/individual make decisions about their conclusions that were based on their evidence?				
Are there better ways for the group/individual to communicate ideas, procedures, or results?				