

Within-Case and Cross-Case Analyses of Questions Posed by Fifth-Grade Students
Working in Small Groups to Investigate Pendulum Motion

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Dedication

This work is dedicated to my son David, my daughter Sarah, and my wife Carol. David has taught me how to apply fairness, justice, joy, and humor to many situations. In helping others in neurology, Sarah, through thought and action has made me feel that scientific endeavors and science education advance the common good. Carol's support, practical listening, and insights have been immeasurable.

Abstract

The focus of this basic qualitative research is student questions in an unstructured inquiry setting. Case and cross-case analyses were conducted (Miles and Huberman, 1984) of the questions posed by fifth grade students working in laboratory groups of size three to five students as they investigated pendulum motion.

To establish the conceptual framework for the study, literature was reviewed in the areas of cognitive theory (constructivism, conceptual change, and other theories), approaches to science, and the importance of student questions in the learning process. A review of group work, related studies of student questions and activities and relevant methods of qualitative research was also undertaken. The current study occupies the relatively unique position of being about the questions students posed to each other (not the teacher) at the outset of and throughout an unstructured inquiry activity with a minimum of teacher initiation or intervention. The focus is on finding out what questions students ask, when they ask them, what categories the questions fall into in relation to possible models of the scientific method, student motivation, and what role the questions play as the students take part in an inquiry activity.

Students were video and/or audio-recorded as they did the investigation. They wrote down their questions during one-minute pauses that occurred at roughly eight-minute intervals. The groups were interviewed the next day about their experience. The recordings, question sheets, and interview accounts and recordings were analyzed by the researcher. Accounts of the experience of each group were prepared, and reiterated attempts were made to classify the questions as the main themes and categories emerged.

It was found that students posed their key research question (most typically related to pendulum damping effects) midway through the first half of their activity, after having first met some competence and other needs in relation to measurement procedures and basic information. The main research question typically emerged gradually in an implicitly shared form. It was found that Deci and Ryan's self-determination theory (2000) with the core needs of competence, autonomy, and relatedness, served as a useful tool for categorizing and understanding the role of the questions. Basic questions about procedures in relation to gaining competence with measurement were considered by the researcher to be most prevalent. When compared to, for instance, Lawson's hypothetico-predictive model of doing science (2003a) it was noted that puzzling observations were not necessarily made at the outset, and key questions took place much later in the investigative process than what typical scientific models might suggest.

Further, more focused research in the areas of self-determination theory in relation to student questions as they engage in inquiry could be of benefit in determining the motivations behind student questions. Educational programs that have, as their goal, authentic student inquiry should take into account that student research questions evolve over time as they meet various needs in the process of initiating their investigations.

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Chapter 1: Introduction

This study was designed to provide insight into the origins and types of questions posed by fifth grade students working in groups to investigate pendulum motion.

Relevance and Importance of Questions

The *Next Generation Science Standards* (NGSS Lead States, 2013a), developed by the National Research Council (NRC), the National Science Teachers Association, and The American Association for the Advancement of the Sciences, and published by Achieve, Inc., includes the following passage about the nature of science:

An essential part of science education is learning science and engineering practices and developing knowledge of the concepts that are foundational to science disciplines. Further, students should develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting and analyzing. (APPENDIX H – Understanding the Scientific Enterprise: The Nature of Science in The Next Generation Science Standards, p. 1)

“Wondering, investigating, and questioning” are important parts of the enterprise of science. They form a key impetus for the current study. Since student questions are a critical part of the scientific enterprise that is described by the NGSS, the current study is an attempt to gain more detailed insights into the role that questions play as students do investigations.

Science educators and research scholars are not alone in describing the importance of posing good questions. The topic has been taken up on a more general

cultural level also. Educator Tony Parker (2008) reported on a discussion he had about important job skills with Clay Parker, the President of the Chemical Management Division of BOC Edwards.

Clay Parker stated:

First and foremost, I look for someone who asks good questions.....Our business is changing, and so the skills our engineers need change rapidly, as well. We can teach them the technical stuff. But for employees to solve problems or to learn new things, they have to know what questions to ask. And we can't teach them how to ask good questions – how to think. The ability to ask the right questions is the single most important skill. (p. 2)

The development of question formulation skills is at the core of the work done by Rothstein and Santana (2013). In *Make Just One Change: Teach Students to Ask Their Own Questions* the authors developed a “Question Formulation Technique (QFT)”. Components of the technique are presenting a question focus, rules for producing questions, improving and prioritizing questions, following through with further learning, and reflecting on the learning. The authors have developed specific rules (p. 44) for the process such as “Ask as many questions as you can”, and “Do not stop to discuss, judge, or answer the questions”, with the intended outcome of creating safe spaces for the posing of questions.

The authors developed this framework as an outgrowth of work with a low income community in Lawrence, Massachusetts. They found it of benefit to help parents know what questions to ask when they participated in their children's educational programs. Further, their work has, as part of its rationale, the idea that helping others to develop good questioning skills can be a component of working towards equity and justice in educational settings.

Chin and Brown (2002) succinctly detailed the importance of asking good questions by stating "to know how to question is to know how to learn well" (p. 547). They also note that that "Questioning lies at the heart of scientific inquiry and meaningful learning" (p. 521).

Van Zee, Iwasyk, Kurose, Simpson, and Wild (2001) reported on a series of case studies designed to investigate teacher and student questions in science. These authors interpreted the 1996 *National Science Education Standards* key components about inquiry "to mean that students should be involved in formulating questions to explore" (p.160).

These authors (p. 160) reflected on J.T. Dillon's statement that "student questions rarely occur in classroom settings" (Dillon, 1988). However, their work includes a chart that indicates that, during open ended inquiry sessions, students construct knowledge with one another by asking and explaining, and that student questions occur frequently and spontaneously. Student opportunities to invent and design and to formulate key issues are also presented (p. 162).

Further Motivators for the Study

Personal Interest

This researcher collaborated with two other teachers (Tom Kelley and Paul Terry, (2006) to lead cooperative science research as part of International Baccalaureate (IB) program science instruction while teaching at the American School of The Hague in The Netherlands from 1997 to 2004. Students worked in groups of three to five with each group containing at least one student each who specialized in the sub – discipline of biology, chemistry, or physics. The students worked together to generate hypotheses, plan an approach to data collection, conduct their experiment, analyze their results, and report on their findings to their peers. This teaching and program development experience has shown that students can have a successful inquiry experience. It has also afforded an experiential background as well as an abiding interest in authentic inquiry activities and student questions. This perspective served as motivation to learn more, in a qualitative research based setting, about what happens when students generate questions as they work together in an inquiry science setting.

Pendulum Motion as a Rich Source for Inquiry

Although a non – ideal, simple pendulum (washers attached to a paper clip at the end of a string) may seem to be a routine piece of equipment, it affords opportunities for a rich variety of student questions. As Baker and Blackburn (2005) put it:

It might seem that there is not much to be said about such an elemental system, or that its dynamical possibilities would be limited. But, in reality, this is a very

complex system masquerading as a simple one. On closer examination, the pendulum exhibits a remarkable variety of motions. (preface)

In their book *The Pendulum*, the two authors used the pendulum as a focus for a full college level course that branches into fields such as chaos, quantum mechanics, and superconductivity. There are many subtleties and variations in relation to pendulum motion that students can explore right away on an introductory basis. Students can choose to see how the period of a pendulum at low amplitude depends (or does not depend) on factors such as mass, amplitude, and length. But students can also choose to investigate damping and the gradual diminishing of the amplitude, frictional effects, compound pendula, various aspects of pendulum precession or the elliptical or circular motion of the pendulum, or more fundamentally, what forces make the pendulum work.

In the setting of pendulum motion, there are multiple factors that separate the real from the ideal. One could take the “ideal” to be the frictionless setting where period for small amplitude oscillation depends only on length and the formula is given by $T = 2\pi\sqrt{\frac{l}{g}}$, where T is the period, l is the length, and g is the acceleration due to gravity. Then, distinctions between real and ideal include various forms of friction, lack of a “point mass” as a pendulum bob, small changes in length as mass is added, and other items. These differences between real and ideal are important. Fifth graders have experiences in the real world. They have their own ideals or ideas about motion, gravity, etc., but these ideas might not be based on the frictionless, small amplitude ideal for pendulum motion.

Models of the Scientific Method and Related Research

Many science textbooks outline a linear process for doing science. For instance, the Glencoe McGraw Hill Physical Science iScience text (American Museum of Natural History, Anderson et al. 2012) presents (pp. NOS 6-7) a linear model with some reiterations that includes asking questions, hypothesizing and predicting, testing hypotheses, analyzing results, drawing conclusions, and communicating results. This and many other science models are in some respect related to Lawson's model (2003a) for hypothetico-deductive reasoning; a series of steps, although at times including reiterations, ranging from an initial puzzling observation to hypothesis confirmation. The current study compared student actions and questions to the Lawson model.

Research has been done (Quinn, 1971, Wright & Fowler, 1975) on question and hypothesis formation in a setting that includes a framing or discrepant event presented by the teacher. For instance, Wright (1981) investigated the relationship between cue attendance and the quality of student hypotheses generated. In these studies, students were shown film loops of specific events intended to initiate the inquiry process. Students were to produce hypotheses for these events.

In the current study, as the case studies and comparison of case studies of students generating questions unfolded, a key goal was to list and analyze the questions that were posed by students, and to see whether they could be related to stages of scientific reasoning.

This introduction serves to illustrate that the ability to formulate relevant and valuable questions is important in the science classroom, the workplace, and in society at large. Leaders in science education and other fields are emphasizing the importance of helping students learn how to formulate good questions.

Purpose of the Study

The purpose of this basic qualitative research study is to employ case and cross-case analysis techniques to gain insight into what happens when students undertake inquiry without a specific starting question from the teacher. Although the pendulum materials and overall lab setting provided an implicit focus, there was a broad range of possible questions and actions that could take place. The search for information about the questions students posed in this setting was motivated by the idea that perhaps this researcher and others could learn about what is important to the students and the progression of student actions and thinking during an open ended inquiry activity. This information is of potential value in helping to guide decisions about further research and practice in inquiry education. Because the pendulum affords such a rich variety of inquiry opportunities with relatively simple equipment, and since there is an abundance of past research (Inhelder and Piaget, 1958) on student work with pendula, pendulum motion was selected as the topic for student inquiry. The researcher did not make the assumption that students would seek to confirm the relationship between period and length. The method of the study left the door open for students to seek more beginning information, such as how long a pendulum swings before it stops or how a pendulum swings.

At the outset of this study, the researcher wondered how well student actions and questions would fit previously developed models of doing science, such as Lawson's hypothetico-predictive model. It was of value to see to what extent, if at all, the

questions tracked along this model of science. The intent of the study is to produce a realistic portrayal of the actions that took place. Furthermore, all questions posed by students throughout the process were investigated; not just the key research question that they might have posed.

What fifth grade students do in an inquiry setting may or may not match the approach to scientific reasoning outlined by Lawson (2003a) at the start of the next chapter below. Nevertheless, in terms of acknowledging point of view, it is important for this researcher to note at the outset that the hypothetico-predictive framework developed by Lawson served as one of the conceptual tools selected to analyze the student questions that emerged. Furthermore, the Lawson model provides important vocabulary and structure for interpreting the actions and questions of the students. Lawson (1982, 2003a), Lawson et al. (1991), Lawson, Drake, Johnson, Kwon, and Scarpone (2000) have studied both the methods of doing and of learning science; this combination is useful to the main themes of this study.

The current study began with the placement of strings, masses, etc. and a directive that students were to ask questions, do an experiment, and see what they could learn about pendulum motion. Therefore, the current study differs from many inquiry research efforts (briefly described above, and elaborated upon in chapter 2) in that the student is at or before step one, in the position of searching for variables of interest and relationships between variables, followed perhaps, but not essentially, by an explanation. This key “first step” of doing science is more emphasized in the current study than in previous research.

Chinn and Mulhotra (2002) have indicated the importance of providing students with opportunities to do authentic inquiry. They noted that there are very few (if any) true open inquiry materials in science textbooks and curricula. The current research, conducted in a fifth grade environment with variables and questions that are not pre – selected or defined by the teacher, is intended to be one component of all efforts in the direction of helping educators to understand how to better provide authentic inquiry opportunities for students.

Research Questions and Context

The importance of questions in science inquiry settings and more general educational and societal questions serves as a key motivator for the current study.

Fifth grade students worked in groups of four to investigate pendulum motion. They were given pendulum materials and measuring equipment. They were then informed that they were to come up with questions and investigate these questions to see what they could learn about pendulum motion. No further direct interventions by the researcher or teachers took place (with the exception of essential classroom management actions such as those related to safety or very general procedures). Within this context, the following research questions were investigated:

1. What questions do the students ask?
2. What types of patterns exist (if any) in the questions that are posed?
3. In what way do the questions provide evidence of abductive reasoning?

Overview

Chapter two reviews the literature related to student questions, methods of classifying questions, methods of qualitative inquiry, potentially relevant cognitive theory, motivational needs, and research similar to the current study. Chapter three is a description of the qualitative research method used for this study. Chapter four is an analysis of the observations made along with the development of assertions in relation to the research questions and observations. This paper concludes with a discussion of the results as well as the limitations and potential implications of this study.

Chapter 2: Review of the Literature

This chapter is a review of literature in the areas of models of the scientific method, methods for learning the process of doing science, cognitive theory in relation to science education and inquiry, group work, science discourse and questions, studies similar to the current study, methods of classifying questions, and methods of doing qualitative research. These areas of research are relevant to the current study because they help to establish a background of knowledge for interpretation of the student questions and actions as they investigate pendulum motion. The goal is to portray the conceptual toolkit that was available to this researcher as context in developing the experimental methods and analyzing and interpreting the data.

Awareness of models of doing and learning how to do science is essential in understanding the study. Various elements of cognitive theory provide a framework that helps with insights into student thinking during the activity. Motivation theory, including self-determination theory, is included in the section on cognitive theory. The fact that the students worked in collaborative groups necessitates a look at the literature in this area. Since questions form an important part of the process of science dialog and argumentation, it is important to examine the increasingly prevalent work in this realm. To understand the design and approach to data collection and analysis that emerged during this study, a review of similar past studies and approaches to qualitative inquiry is helpful.

A framework that can be helpful for interpreting this review of the literature is the “method of multiple working hypotheses”. Chamberlin (1890) developed this approach

and noted “the multiple character of its genetic conceptions and of its tentative interpretations” (p. 92). Chamberlin referred to the idea that when a study is undertaken, one can take the approach of allowing for multiple hypotheses to be held in the investigators mind, rather than establishing one particular hypothesis at the outset. This is consistent with the idea that “an adequate explanation often involves the co-ordination of several agencies, which enter into the combined result in varying proportions” (pp. 92-93).

In the current study, it is perhaps more of benefit to consider the development of “multiple conceptual tools” as opposed to “hypotheses”. It is not the aim of the study to validate a given cognitive model. Rather, it was deemed important for this researcher to be conceptually prepared, in as broad a sense as is realistically possible, to interpret the student actions and questions that could occur in the study.

Models for Doing and Learning How to do Science

In developing the design of the study, this researcher reviewed various models of science in order to find a model that could be used to help frame the flow of student questions and actions in the study.

Lawson's Hypothetico-Predictive Model and Related Comments

Lawson (2003a) has developed and described the following seven elements of the hypothetico-predictive model of scientific learning:

1. Making an initial puzzling observation.
2. Raising a causal question.
3. Using analogical reasoning to generate one or more probable hypotheses.
Analogical transfer, or analogical reasoning involves borrowing ideas that have been found to “work” in one or more past related contexts and using them as possible solutions/hypotheses/guesses in the present context.
4. Supposing for the sake of argument and test, that the hypothesis under consideration is correct. This supposition is necessary so that a test can be imagined with relevant condition(s) that along with the hypothesis allow the generation of one or more predictions.
5. Carrying out the imagined test. The test must be performed/conducted so that its predicted result can be compared with the observed result of the actual test.

6. Comparing predicted and observed results.....A good match means that the hypothesis is supported, but not proven, while a poor match means that something is wrong with the hypothesis, the test, or with both.....
7. Recycling the procedure. The procedure must be recycled until a hypothesis is generated, tested, and supported on one or more occasions. (p. 197)

Lawson (2003a) further illustrated and validated this model with direct, personal accounts written by Galileo Galilei (1610, translated and reprinted in Shapley, Rapport and Wright, 1954, p. 59). The accounts relate to Galileo's discovery of the moons of Jupiter, and include the key initial passage "At length, by sparing neither labor nor expense, I succeeded in constructing for myself an instrument so superior that objects seen through it appear magnified nearly a thousand times"(p.58).

By constructing a new, improved lens, Galileo was then in a technical position to make the "puzzling observation" that is step one of Lawson's hypothetico-predictive model. And, Galileo's background knowledge of the heavens gave him the "conceptual lenses" that were necessary to first be puzzled, and then to generate a hypothesis to explain his observations. Then, Galileo planned and conducted observations to gain data that would help him further refine his thinking. Ultimately, he came to the conclusion (made the discovery) that there are moons orbiting Jupiter.

The descriptions above, when related to student activity in the current study, serve to introduce important elements of this study. First of all, in comparing Galileo's efforts to Lawson's hypothetico-predictive model, it can be noted that a key step for Galileo, before Lawson's step 1, was to build a relatively powerful telescope. This, combined

with Galileo's background knowledge, allowed him to wonder about what he observed. But often (Roth, 2006) students do not have the conceptual lenses, or the background knowledge, to be puzzled about what they see. This, in turn, could hinder their ability to effectively generate scientific hypotheses that would enable them to follow through with successive iterations of the hypothetico-predictive model.

Other Models for Doing Science

Lawson's model can be compared to the development of a model for doing science and engineering established by the NGSS ((NGSS Lead States, 2013b).

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

(NGSS, Box 3-1, Practices for K-12 Science Classrooms)

This model allows for a broad range of scientific activity. But Lawson's model and the Next Generation Science Standards framework both include the posing of a question

at the initial stages of the scientific process. The current study is about questions that are asked during this initial phase (and perhaps even “before the beginning”), and throughout the inquiry process of designing and performing an experiment in an educational setting. As noted in Lawson’s model, there are successive iterations and regenerations of questions and hypotheses as the scientific process unfolds, so it was of interest to learn about the types of questions that would be asked as student activity progressed and potential iterations took place.

Lawson (2010) provided comprehensive and detailed descriptions of methods of teaching science in his work *Teaching Inquiry Science in Middle and Secondary Schools*. These methods are presented within the context of evidence and theory grounded research about learning and the nature of science. Early on in the work Lawson (2010) characterized the process of doing science with this account;

By tagging young salmon, biologists discovered that mature salmon actually return to precisely the same headwaters where they were born years earlier! The discovery of this pattern (what scientists would call the law of salmon navigation and reproduction) raised a very interesting causal question: How do salmon find their home streams? (p. 12)

This passage portrays the development of a causal question from a puzzling observation. As this chapter in Lawson’s work unfolds, Lawson gives a detailed description of the hypotheses and experimental design that was developed to investigate the causal question. A further area of analysis, though, could be done in the realm of activity that came before the puzzling observation. Perhaps this puzzling observation took place in

light of results of earlier investigations, or in the context of ongoing fascination by scientists with the behavior of salmon. In any case, there may have been some “pre-puzzling observation” activities that took place. The current study was deemed to have the potential to afford a glimpse of these “pre –inquiry” or “pre-puzzle” activities. It is acknowledged, though, that any scientific endeavor has a starting point based on, perhaps, previous iterations of Lawson’s model.

There are models of the scientific process that are less linear and more community based and holistic. For instance, the Berkeley “Understanding Science” course developed by the University of California Museum of Paleontology (2013) provides the following comment about the nature of scientific inquiry:

As opposed to the simple recipe of the linear scientific method, the *real* process of science is exciting, iterative, nonlinear, nuanced, depends upon the scientific community, and is intertwined with the society at large. The *real* process of science proceeds at multiple levels and sorts through many ideas, retaining and building upon those that work. (How Science Works)

The same organization has developed a diagram for the process of science as portrayed in the figure below.

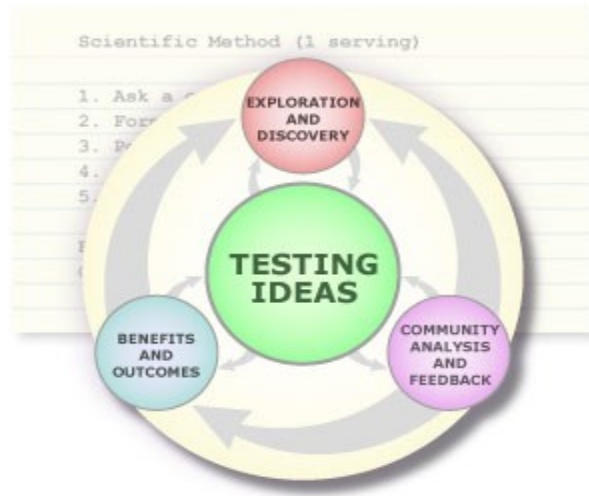


Figure 1 “Summing up the Process” (2013). This figure is the UC Berkeley “Understanding Science” group’s model for the process of doing science. University of California Museum of Paleontology (2013).

Krajcik et al. (1998) proposed a non – linear model called the “Investigation Web” that included five interwoven components that those doing science move around. One component of Krajcik’s five is “Asking questions: making predictions, drawing on background knowledge, judging worthwhileness and feasibility” (chart p. 516). Note that the five aspects were those investigated by Krajcik in a study of student inquiry in the middle school.

Finley and Pocovi’s Reflections

In a chapter in a 2000 book on Inquiry edited by Minstrell and van Zee, Finley and Pocovi (2000) state at the outset that

The purpose of this book is to encourage the teaching of scientific inquiry. In order to do so properly, we need to understand the nature of scientific inquiry and

to reconsider some of the common conceptions associated with what the phrase “scientific inquiry” means. (p. 47)

The authors follow through with a review of traditionally cited components of the scientific method with comments about the extent to which these components are (or are not) present in actual scientific research. The content and method used by Finley and Pocovi inform the current study.

From a content standpoint, the authors’ analysis of the “recognize and research the problem” traditionally recognized component of the “scientific method” with consequent recommendations is most useful. They note in their recommendation that “students should be taught that what counts as a scientific problem depends upon what theories or initial ideas about the natural world are being used; and that there are two primary types of scientific problems – empirical and theoretical” (p. 55). The students in the current study were expected to bring a variety of initial ideas to their investigation. The distinction between empirical and theoretical problems is important – as youngsters inquire about the natural world, they may pose big picture theoretical questions about the pendulum as well as detailed questions perceived to be researchable within the 45 minute period.

Finley and Pocovi’s discussion about the oft assumed cornerstone of the scientific method – namely “Form a hypothesis – a statement that can be tested” is particularly relevant to a study of student questions in science. The authors note that “the formulation of the hypothesis about how some natural phenomenon works – that is, predicting what will happen if – is a major part of the fun and excitement of scientific inquiry, but the

inquirer must be conceptually prepared to do so” (p. 56). The author of the current study notes that in order for an anomaly to be perceived, the inquirer must possess a mindset that causes some phenomena to stick out in a conceptual landscape. Constructivism, conceptual change theory, and Roth’s (2006) “singular plural theory” are different ways of thinking about how this landscape is developed and referenced as questions are formed by the inquirer. In the current study, the researcher had to be realistic about what questions could be possibly formed given the background (or lack thereof) of the students with respect to pendulum motion. Students are perhaps most likely to ask questions that lie within domains that they are familiar with.

The work by Finley and Pocovi provides a model for method of presentation that can assist the current study. The authors use the “traditional scientific method” as a backboard, frame of reference, and entry point for their discussion about what actually happens in science and what recommendations will help science educators facilitate student inquiry.

Similarly, the current study will use Lawson’s hypothetico-predictive model as an entry point and frame of reference to help to develop the study and analyze the student questions in the activity. Although the questions posed might or might not fit into the model, the vocabulary and overall conceptual framework are important features of the background knowledge this researcher brought to the activity; they provide an important starting point for the emerging design of this qualitative study.

Lawson’s work, combined with NGSS documents and other research cited above, indicates that there are many different models for doing science.

In 2005, the National Institute of Health (NIH) combined with the Biological Sciences Curriculum Study (BSCS) to publish a document entitled “*Doing Science: The Process of Scientific Inquiry*” that developed the “Five E” model (Engage, Explore, Explain, Elaborate, Evaluate). As a reference point, the NIH established a model for science by stating:

Science proceeds by a continuous, incremental process that involves generating hypotheses, collecting evidence, testing hypotheses, and reaching evidence based conclusions. Rather than involving one particular method, scientific inquiry is flexible. Different types of questions require different types of investigations. Moreover, there is more than one way to answer a question. Although students may associate science with experimentation, science also uses observations, surveys, and other non-experimental approaches. (p. 1)

This overview of various descriptions of how science is done can be summarized by noting that there is a spectrum of possible interpretations of science, from the more linear, step by step, but still iterative model proposed by Lawson, to the more community oriented, holistic model described in the Berkeley science series. It is apparent from the literature that there is a growing realization that there are many different ways to do science, yet there are some central themes of developing hypotheses, collecting evidence, testing hypotheses, and reaching evidence based conclusions. To distill this view of science down even further, a working definition for a middle school science teacher could be contained in a quote from Finley and Pocovi (2000) “As Galileo and others found out,

the idea that an individual could come to know the world through the use of the senses and reasoning was not popular with the church and government of the age” (p.49).

The “come to know the world through the use of the senses and reasoning” is a flexible, fundamental way of thinking about science as an educator working with children. For this study, it will serve as the most parsimonious way to view the actions of the students as they do their activity with pendulum motion. As an educator, it is a realistic, tangible, practical mindset to use in working with children doing science inquiry. However, as students learn how to do science, they must also develop more specialized reasoning skills, vocabulary, and techniques (Driver, Asoko, Leach, Mortimer and Scott, 1994; Mortimer and Scott, 2003). Furthermore, it is perhaps not an accident that the above quote is set within a context of using senses and reasoning versus going by the authority. The current study examines how students develop the use of their own reasoning skills in the framework of working within a structure set by their authority. How students negotiated the boundary between authoritative “what are we supposed to do?” questions and “What do I see and how do I make sense of it?” was perceived by this researcher to be a potentially important part of classifying questions in science. Perhaps students would need to learn that personal opinion, or authority based thinking, is not a “scientific” way to determine how the world works. And finally, in terms of making a decision about what framework of science to use in looking at the entire sequence of student questions, Lawson’s hypothetico-predictive model was utilized due to its specific, detailed accounts of what happens at each stage of the scientific process; this provides a tangible frame of reference in tracking the flow of student questions through the activity.

Further Studies and Abductive Reasoning

Kwon, Jeong, and Park (2006) studied abductive reasoning in relation to student generation of hypotheses in a setting where fifth graders attempted to relate pendulum ideas to a problem about children on a swing set. They cited Hanson (1958) and Lawson (1995) and others in defining abductive reasoning as “the mental process of generating hypotheses in which an explanation that is successful in one situation is borrowed and applied as a tentative explanation in a new situation” (p. 644). They undertook a study which showed that not all fifth graders who successfully identified length as the critical factor in determining the period of a pendulum were able to apply this knowledge to forming a relevant hypothesis about a swing set problem. These researchers developed categories for the hypotheses developed on the basis of variables selected by the students. Note that in this setting, the stage was set for the students. They were given a defined setting with a general question about a swing set and asked to generate hypotheses. This researcher is interested in studying the steps prior to the hypothesis formation. What questions would students ask on a more preliminary basis when provided with pendulum materials but not given a more specific direction for research? Nevertheless, Kwon et al.’s identification of the importance of abductive reasoning informs a research question for this study. Abductive reasoning concepts could help to identify the precursors to the “Aha!” moment of making connections that lead to a testable question that could exist in the question formulation process.

Models for Learning Science

Lawson (2010) has described three different types of student learning cycles that can take place during inquiry activities. The first of these, the Descriptive Learning Cycle, answers descriptive who, what, when, and where questions and “seldom provoke much argumentation” (p. 103). Nevertheless, these activities could form an important part of the inquiry process. The second process is the Empirical-Abductive Learning Cycle, where a hypothesis is formed through a reasoning process called abduction and the hypothesis is tested through data previously gathered. Lawson noted “this “hitting” on the right idea involves the use of analogy to borrow ideas from past experience” (p. 105). Lawson then introduced the Hypothetico-Predictive Learning Cycle that includes many of the components of the Hypothetico-Deductive model of doing science, including devising a method to test a hypothesis which generates new data.

Chinn and Mulhotra (2002) developed a grid that describes the elements of authentic inquiry. This framework emphasizes that in authentic inquiry, scientists generate their own research questions, select their own variables, and devise analog models to address the research question. They contrasted authentic inquiry with inquiry activities where questions, etc. are provided to the students. In the current study, the variables are not preselected and the questions are not given to the students.

Driver et al. (1994) synthesized key constructivist approaches with the comment:

We now consider what we see as the implications of the distinction between common sense and scientific reasoning for the learning of science. We have argued that learning science is not a matter of simply extending young people’s

knowledge of phenomena - a practice perhaps more appropriately called nature study - nor of developing and organizing young people's common sense reasoning. It requires more than challenging learner's prior ideas through discrepant events. Learning science involves young people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims. Before this can happen, however, individuals must engage in a process of personal construction and meaning making. (p. 8)

This cornerstone passage, and other comments in the article, set a broad context for the motivation behind this study. The efforts of one or two classes of students as they investigate pendulum motion and ask questions will hopefully add one data point to the knowledge base that helps students to construct meaning through engagement in inquiry activities. At the same time, students in the study might not possess the specialized vocabulary or scientific thinking skills needed to approach their pendulum activity scientifically. And finally, this passage, along with follow up comments in Finley and Pocovi's (2000) articulations of authentic processes of doing science, make it clear that although "using the senses and reasoning skills" is a good starting point for learning science, doing science is a more complex activity than the phrase implies.

Group and Collaborative Learning

Johnson and Johnson

Johnson, D.W., and Johnson, R.T. (1975) published a pivotal work on cooperative learning entitled *Learning Together and Alone*. In this work, the authors compared the benefits of cooperative, competitive, and individual learning. A large number of affective benefits of cooperative learning were described including interpersonal skills; group skills for “humanness”; pluralistic, democratic values; acceptance and appreciation of cultural, ethnic, and individual differences; reduction of prejudice and bias; valuing education; positive attitudes toward school, subject area, instructional activities, school personnel, and other students; enjoyment and satisfaction from learning; moderation of levels of anxiety to promote learning; positive self-attitudes; and the development of emotional capacity (p. 35). The authors listed cognitive outcomes of cooperative activities (p. 32) as retention, application, and transfer of factual information, concepts, and principles; mastery of concepts and principles; verbal abilities; problem – solving ability and success; cooperative skills; creative ability; divergent and risk – taking thinking; productive controversy; awareness and utilization of one’s capabilities; and perspective (role- taking) abilities. Johnson and Johnson mentioned, in 1975 that “the research suggests that teachers are presently overusing competition, possibly misusing the individualistic goal structure, and underusing cooperation in their classrooms” (p. 25). This pivotal work gave rise to numerous studies and the development of group based instructional activities in the decades that followed.

In 2000, D.W. Johnson, R.T. Johnson, and Stanne presented a meta-analysis of cooperative learning methods. They concluded that “the consistency of the results and the diversity of the cooperative learning methods provide strong validation for its effectiveness” (abstract).

More Recent Studies

Cohen (1998) discussed strategies for eliminating and minimizing status differences that can affect group work. She emphasized the importance of “using a multiple abilities treatment and assigning competence to low status students” (p.20).

Crawford, Krajcik, and Marx (1999) investigated the nature of a middle school classroom during the development of a “community of learners”. Building on a principle of “active construction” (p. 702) as well as Vygotsky’s view that knowledge is collaboratively constructed from interacting with others, and drawing from collaborative learning literature, the researchers identified the following six components of a community of learners.

1. Instruction is situated in authentic tasks.
2. Students develop interdependency in small group work.
3. Students and teacher debate ideas and negotiate understanding.
4. Students and teacher publicly share ideas with members of the classroom community.
5. Students collaborate with experts outside the classroom.
6. Responsibility for learning and teaching is shared. (p. 703)

The investigators designed a course of instruction, taught the course, and examined what happened in the course. In an experimental design that included some components of the current study, such as the observation of seven teams of students with one focus group that was videotaped, the investigators developed the classifications of traditional intermediate, and constructivist to discuss important group learning characteristics. They also noted that collaborative interactions were increased when tasks were student-initiated, and that student dialogue often centered on procedural aspects of the activity when completing teacher designed activities.

Earlier in this review, an NIH/BSCS (2005) document was cited in relation to methods of doing science. This work also emphasized that “when active, collaborative learning is directed toward scientific inquiry, students succeed in making their own discoveries”. Note that this statement is based on program development and an overview of literature, and not a detailed research program. Nevertheless, in tracking the flow from the early Johnson and Johnson work to more recent literature, one can observe a trend from the general group statements in 1975 to more specific science program development in group work that typically validate and articulate the general themes developed by Johnson and Johnson. Furthermore, as group work becomes more prevalent, teaching techniques that enhance equity in group work become increasingly relevant.

Various cooperative learning programs have been developed over the last several decades. The Process Oriented Guided Inquiry Learning (POGIL) program, initiated by Rick Moog (Farrell, Moog, and Spencer, 1999), was developed by chemistry teachers in the mid 1990’s. The POGIL (2014) website home page details the approach that includes

“a learning cycle of exploration, concept invention, and application”. The POGIL program includes specific roles for group members, typically at the secondary or post – secondary level, as they learn to work effectively as part of a collaborative team. The roles are group manager, recorder, spokesperson, and strategy analyst.

In developing the plan for this study, this researcher considered the option of attempting to learn about possible effects of group role on the types of questions posed. It was determined that it would be not practical to do so. Furthermore as pointed out by Oliveira, Boz, Broadwell, and Sadler (2014) in the abstract to their article, “educators have sought to structure collaborative inquiry learning through the assignment of static group roles. This structural approach to student grouping overlooks the complexities of peer collaboration and the highly dynamic nature of group activity” (p. 281).

In the current study, group roles were not assigned in light of the large potential for fluidity in the roles and the reality that specific group roles were not previously developed in the school.

Clearly, group work and collaborative learning are important aspects of inquiry science. There is ample evidence at the scholarly, research level that group work can enhance learning. There is also an increasing prevalence of work that has been done to promote, on a more practical level, the use of collaborative activities in the classroom.

Many of the models for science above assume or state a community as a key component of the process of doing science. In the current study, the groups of three to five students, within the context of a classroom of 24 students, provide the group and the community setting for the inquiry activity.

Cognitive Theory and Related Topics

Since the current study is about student questions, and the questions could be considered to stem from thoughts students have as they interact with equipment and ideas, a review of some key concepts of cognitive theory is presented. Knowledge of various models of how students learn informs the study of just what happens when students ask questions during an inquiry setting.

Constructivism and Related Theories

Summaries, like that done by Harlow et al. (2006) of Piaget's constructivist paradigm are often referenced because Piaget's original works articulate the constructivist paradigm in a developmental manner, without the direct label of constructivism. For instance, although the term "constructivism" is not directly used by Piaget in his 1952 work *The Origins of Intelligence in Children*, the terms, assimilation, equilibrium, and accommodation are used as he develops constructivist concepts. The quotes below are examples of this development. In describing how learning occurs, Piaget (1952) noted that "the organism is a cycle of physicochemical and kinetic processes which, in constant relation to the environment, are engendered by each other" (p.5). His core statement that "adaptation is an equilibrium between accommodation and assimilation" (p.6) is an essential component of constructivism. Piaget's development of constructivist theory is very biological in its nature; learning occurs when a stimulus is first assimilated, that is to say, incorporated without significant reorganization of cognitive structure, and then, through reorganization, accommodation takes place.

Lawson's Model, Constructivism, the Hypothetico-Predictive Model and Related Studies

Lawson et al. (1991) suggested that a student's academic difficulties can be connected to reasoning difficulties. The authors described the constructivist hypothesis that the acquisition of domain specific knowledge (declarative knowledge) requires the use of general procedural knowledge. They defined this key term by noting "Constructivism...means that the learner personally constructs his/her knowledge of the external world and that this knowledge depends as much, if not more, on the learner's actions (mental and/or physical) as it does on the nature of the external world" (p. 955). From the basis of constructivism, Lawson then introduced a key concept:

hence hypothetico-deductive reasoning is being defined as that pattern of reasoning in which intuitively generated ideas are proposed as hypotheses, their consequences deduced, and evidence of some sort is compared with those deduced consequences to allow the rejection or retention of initial hypothesis. (p. 956)

Lawson then did a study that supported the idea that reflective thinkers, those who could use hypothetico-deductive reasoning, were most successful in concept acquisition compared to those who did not have this skill. From this evidence, the constructivist hypothesis is supported, and hypothetico-deductive reasoning is the procedure that leads to domain specific declarative knowledge. Lawson's work in this area can be considered an adaptation and application of the constructivist paradigm.

An important question related to this work is "under what conditions are students capable of conducting inquiry entirely on their own?" Alternatively, "what is the role of

the teacher in the student process of constructing learning?” Lawson (2003a) explicates Piaget’s concept of self-regulation to describe the role of the teacher in this setting.

Lawson mentioned that in some cases, learners are able to respond to environmental pressures and acquire a new behavior without truly integrating the behavior with previous ways of thinking. In contrast, there are times when, through self-regulation, the learner’s mental structure is accommodated to allow the complete assimilation of the input. In this case, the learner is able to adapt well even without continued environmental pressure.

Lawson adapted constructivist theory (while noting the importance of teaching techniques) with some implications of self-regulation theory for teaching. He noted that the teacher, instead of “sitting idly by waiting for change” (p.21) can “produce environmental pressures that place students into positions in which they can spontaneously reorganize their thinking along the path toward more complex and better adapted thought process” (p.22).

For the class period of the current study, it was intended that the instructor would indeed essentially sit “idly by” with the exception of general instructions and safety and behavior reminders; intervention was at a minimum in an effort to gain a clear view of what would take place in this type of setting. Nevertheless, the research itself, the placement of pendulum materials, and the prompting to write questions down at regular intervals that took place in this study could be considered interventions that assist with self-regulation.

Distinction between Hypothetico-Predictive and Hypothetico-Deductive

Lawson (2003b) made the distinction between hypothetico-predictive argumentation and hypothetico-deductive reasoning by noting that “because generating predictions may involve a creative element (i.e. more than an automatic and ‘logical’ act of deduction), the overall pattern of argumentation depicted in figure 2 is labeled *hypothetico-predictive*, rather than hypothetico-deductive” (p. 1392).

Lawson’s hypothetico-predictive model is shown in figure 2 on the following page. Note that although there is a relatively linear flow, there are iterations based on the results of the tests that are performed.

The model forms a link from constructivist processes described by Piaget to the “scientific method” of hypothesis/data collection/confirmation or falsification. One question that arises, at this point, then, is “If the scientific method is similar to the way children naturally construct meaning of the world, why is it so difficult for children to successfully engage in inquiry activities?” Certainly the fact that students have this difficulty does not refute constructivism as a valid model. As other cognitive models of learning are examined, and as research about how children are best supported by teachers during the inquiry process is reviewed, constructivist processes will be referenced as a helpful guide. For instance, the researcher had to be aware of the potentiality that students in the current study would not “make a puzzling observation”. This could potentially be the case because students might not see anything in their environment that

initiates disequilibrium. Further developments in learning theory have followed from the constructivism model, perhaps most notably conceptual change.

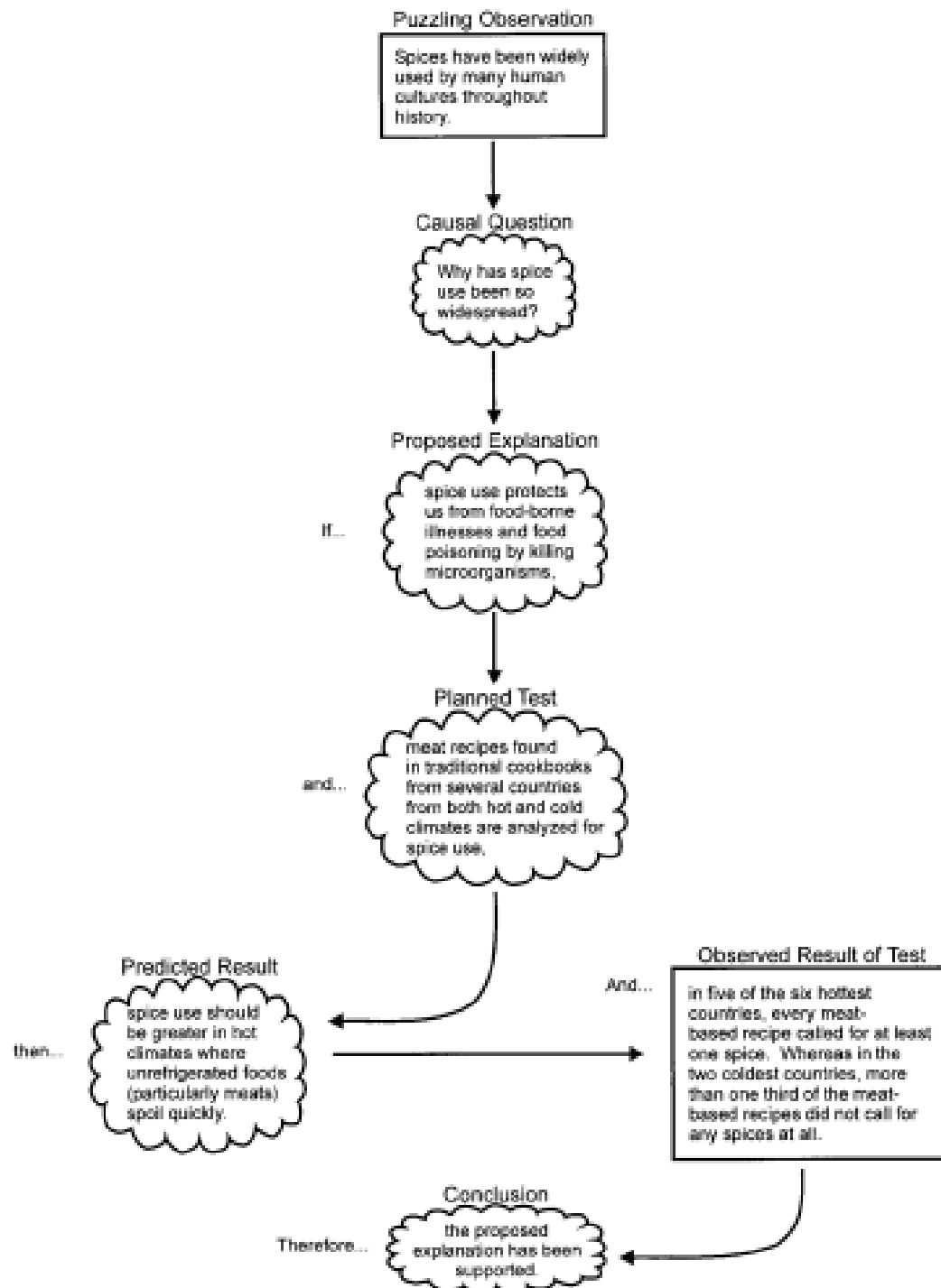


Figure 2. Lawson's Hypothetico-Predictive Model: An Example

Lawson 2003b, (p. 1391)

Conceptual Change Models

Posner, et al. (1982b) began an article on conceptual change by referring to Ausubel's 1968 work with the statement "learning is the interaction between what is taught and ...current ideas or concepts" (p.211).

The article described the importance of studying students' misconceptions and ideas and theories related to this topic. They mentioned that "Although Piaget (1974) developed one such theory, there appears to be a need for work which focuses more on the actual content of the pupil's ideas and less on the supposed underlying logical structures" (Driver and Easley, 1978, p. 76). The authors then related "two distinguishable phases of conceptual change in science" (1982b) to "analogous patterns of conceptual change in learning" (p. 212).

Posner et al. then (1982b) identified conditions for their type of accommodation (within both the scientific and individual learning realm) to occur:

- 1) *There must be dissatisfaction with existing conceptions...*
 - 2) *A new conception must be intelligible.....*
 - 3) *A new conception must appear initially plausible.....*
 - 4) *A new concept should suggest the possibility of a fruitful research program.*
- (p.214)

This article on conceptual change follows the pattern described earlier of adapting Piaget's constructivism and terminology. And, it again relates the process of thinking as

a scientist to learning about science. Indeed, the learner and the scientist are used almost interchangeably in the description of accommodation.

In a later article, Posner and Strike (1990) revised their outline for conceptual change, and they noted that “we (authors) did not claim that all learning involves this form of conceptual change” (p.148). Five revisions (consideration of a wider range of factors, current scientific conceptions and misconceptions, which can exist in different modes of representation, the need for a developmental view of conceptual ecology, and an interactionist view of conceptual ecology) are presented with educational implications.

Luque (2003) related domain specific knowledge to a student’s ability to enact intentional conceptual change:

A strong restructuring of individuals’ knowledge is effortful, time demanding, and requires individuals to be highly engaged in the task. It also requires individuals to consider change as relevant and useful. They must consider learning as a personal goal, and a certain amount of domain – specific knowledge is required.
(p. 164)

Luque’s chapter in “Intentional Conceptual Change” described how the existence of domain specific knowledge is an important starting position for conceptual change to occur as students learn. Not directly included in Luque’s and most other accounts of conceptual change, is the specific link between domain-specific knowledge and the ability to formulate a good quality scientific hypothesis. The current study intended to take a relatively microscopic look at one link in the chain of learning about science

concepts; the link between background knowledge and generating a testable scientific hypothesis.

Jensen and Finley (1995) used historical materials to teach evolution. They measured pre- to post-test gains on Likert items and multiple choice questions. They conducted a key conceptual trace analysis (complete Darwinian conception, correct but incomplete conception, functional misconception, missing conception).

Within this work, a solid definition, formulated by Posner (1982b) of conceptual change and described at the initial stage of this review was referenced. In this case, the definition and use of conceptual change was more learner than scientist centered. In using the historical approach to learning, students were able to first identify Lamarckian (invalid) evolution concepts because these were prevalent and by solidifying these they could be more easily challenged and changed. The Darwinian approach was then presented. In the current study, students had the potential opportunity to identify the concepts that are challenged by the observations they made while doing their experiment. One implication of conceptual change models for educators planning inquiry activities is that it is important to consider the background knowledge that students will bring to their investigations. Furthermore, linking some of Lawson's (2003b) comments about the importance of teacher intervention or pressures, it could be important for a teacher to guide the students to discover aspects of their current understanding that do not adequately explain the phenomena they are considering.

Gunstone (2000) wrote an overview of constructivism and learning research in science education. Again, Piaget's work was mentioned early in the article. But,

Gunstone then introduced the work of Rosalind Driver and others as being more related to classroom practice and less directly related to Piagetian models. After duly noting (Gunstone, 2000) “While it is clear that Piaget’s concerns in his research were not focused on classrooms, it is also certain that some of the research that derived from Piaget was motivated by concerns with the quality of learning and teaching in science classrooms”(p. 255), Gunstone then discussed Driver’s 1973 Ph.D. thesis and noted that “Central to the conclusions and interpretations of this study was the significance of the concepts or content that the student was to learn....Her study was explicitly located within the context of the children’s usual classroom and curriculum” (p. 255).

Gunstone further underscored his description of the work of Driver and others by noting that “(1) constructivism as it is elaborated today *was not a central initiating theory for any of these groups*; (2) the motivations of these researchers were derived from classroom concerns with the quality of student learning in science” (p. 257). Driver’s work was then further articulated:

In her doctoral thesis she argued the then radical position that students’ interpretations of phenomena were for them coherent frameworks of ideas derived from interpretations of their experiences rather than “mistakes” resulting from their inability to learn. She also argued that student learning was dependent on already-existing ideas held by the student rather than being limited by the intellectual development of the student. (p. 261)

Therefore, Driver’s ideas relate conceptual change theory, background information, and actual classroom practice. Her further work also introduced the idea of

learning science as social construction of knowledge. Driver described the importance of authority (in Gunstone, 2000, p. 266) in mediating learning experiences. And, her emphasis is on the content of science. Gunstone (2000, p. 268) cited a quote from Driver et al. (1994):

..... The point is that, even in relatively simple domains of science, the concepts used to describe and model the domain are not revealed in an obvious way by the “book of nature.” Rather they have been invented and imposed on phenomena in attempts to interpret and explain them, often as results of considerable intellectual struggles. (p. 11)

In relating to Popper’s (1972) “worlds”, Driver emphasized science concepts as “world three” ideas that are to be taught to the students. Perhaps, however, Piaget and Lawson might have described how students and scientists further their knowledge of “world one” natural phenomena. In the first case, Driver placed an important emphasis on the transmission of knowledge. In the second case (Lawson/Piaget) the emphasis may be on the creation of knowledge. Although there is overlap between the two approaches and both relate to constructivism, the distinction was deemed to be of potential importance in interpreting the students’ actions in the current study, particularly in light of the lack of teacher intervention inherent in the design of the research. A strict (perhaps overly strict) application of Driver’s model could make one skeptical that much learning would happen during the class period in the current study.

Vygotsky and Social Constructivism

Lev Vygotsky (1896-1934) explored and developed a theory of learning that is now called social constructivism. Although there is some similarity with Piaget's views in terms of the internal process of constructing meaning, Vygotsky emphasized the collaborative, social nature of learning and language. The teacher is an important mediator in the learning process.

In *Mind in Society*, Vygotsky (1978, translated, assembled and edited by Cole et al.) described the term "Zone of Proximal Development" (ZPD) as "The distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86).

The ZPD concept is an important part of Vygotsky's idea that "The problems encountered in the psychological analysis of teaching cannot be correctly resolved or even formulated without addressing the relation between learning and development in school age children" (p. 79). Vygotsky emphasized the value of having educational experiences lead, not match, the students' developmental level. He stated that "the notion of a zone of proximal development enables us to propound a new formula, namely that only "good learning" is that which is in advance of development" (1978, p. 89).

Vygotsky (1978) emphasized that "human learning presupposes a specific social nature and a process by which children grow into the intellectual life of those around them" (p. 88). And although the teacher is viewed as an important mediator, he/she is not deemed to be just a class leader or lecturer, but must also make contact with the student

individually to work effectively within each child's zone of proximal development and internal processes. And finally, Vygotsky concluded his chapter on learning and development with the key idea that "there are highly complex dynamic relations between developmental and learning processes that cannot be encompassed by an unchanging hypothetical formulation" (p. 90).

Two comments can be made about social constructivism in relation to inquiry learning and question formation. First of all, if students are learning in a Vygostkyian, ZPD type setting, then they are in a social context where the ideas that they are being presented are "optimally just beyond" what they can work with independently. Therefore, the students might not be as successful in doing more independent, self guided inquiry with content that is "optimally within their ZPD" as with content that they have already mastered and can work on independently. In this author's own experience, students often "regress" to more beginning, self-understood concepts such as speed or slope when asked to do inquiry in the field. For instance, during the IB science project discussed at the outset of this paper, twelfth graders rarely sought relationships between variables that include more advanced twelfth-grade level physics concepts, even if they had shown some success with these concepts within the supportive social context of the classroom.

Secondly, Vygotsky (1978) mentioned that each discipline may have different relations to the course of child development. This raises the question "Is inquiry, and hypothesis formation, a type of discipline that follows a different developmental course than the acquisition of other scientific content?" Vygotsky (1978) noted that "learning is

more than the acquisition of the ability to think; it is the acquisition of many specialized abilities for thinking about a variety of things” (p.78).

Knowledge of social constructivism, conceptual change, and Driver’s classroom based work was considered by this researcher to be of potential use in interpreting the students’ actions within the context of the group development of the experiment. These frameworks for learning science provided the researcher with a range of conceptual lenses through which the student actions could be observed. Hence, there is some implicit sanctioning within the approach to the study that background knowledge is important in inquiry settings.

Roth’s Singular Plural Model

Roth (2006) noted that students interact with their world to create their lifeworld. Over time, in a sometimes passive way, the learner adds lenses, maps, or transparencies that help them understand their environment.

Also in this work, an aporia, or learning paradox, was presented. How are students supposed to interpret what they are seeing in a demonstration if they do not have the conceptual lenses to see what they are “supposed” to see? Roth’s ideas pertain to the current study because when the lab materials were to be made available to the student, there was the implicit hope that they would see things that could potentially lead to rich investigations, such as how length affects time of swing. But according to Roth’s model, there was no guarantee that students would see these rich opportunities because they might not have known what they are supposed to see and they might not have had the

conceptual lenses, or background knowledge, to see science concepts in the natural world. As was similarly noted after the review of social constructivism and conceptual change, the concepts developed by Roth were considered to be of potential benefit in gaining an understanding of the students' actions and questions as they investigated pendulum motion.

In Roth's book, he noted that the more he interacts with the environment, the more various conceptual layers unfold. Roth gave many helpful descriptions of students interacting with the environment and forming ideas about what they see. He indicated that the "Singular Plural Perspective" provides an alternative to constructivism and conceptual change theory, but it could be construed that he has not refuted these accepted constructs, but has found some helpful insights that help students to get to "step 1" of the hypothetico-predictive process. It is possible that the unfolding of layers may simply mean that there is a time requirement for students to build, or construct their ideas as they interact with the environment.

This "unfolding process" relates to a question one could ask about the current study. How much unfolding could take possibly place over one class period?

Deductive and Inductive Reasoning

Lawson (2005) noted "A long-standing and continuing controversy exists regarding the role of induction and deduction in scientific inquiry" (p.147). Inductive reasoning, or learning from experience, is cited by many (Lee, 2000, p.15, Tidman and Kahane, 2003, p.6) as a key component of scientific reasoning. Others claim that there is

no evidence to suggest that inductive reasoning happens, or is even possible, when scientific knowledge is created.

Since this study concerns itself with the questions student ask, and these questions could lead to a hypothesis, it was deemed to be important to explore the relationship between inductive reasoning and hypothesis generation.

Data collection and analysis is placed in a more meaningful context by a hypothesis. Popper (1965) noted “Observation is always selective. It needs a chosen object, a definite task, an interest, a point of view, a problem” (p. 46). But where does this point of view come from? What background or on the spot experiences help students to generate hypotheses?

Motivation

In Daniel Pink’s popular book *Drive* (2009) three key components of motivation are discussed. These are autonomy, mastery (competence), and purpose (relatedness). Pink identified these three motivational factors in business and educational settings. He referred to the more scholarly work of Deci, Koestner and Ryan’s “Self-Determination Theory (SDT)”.

In a review of a meta-analysis of studies on intrinsic motivation, Deci, Koestner, and Ryan (2001) concluded that:

Specifically, the results indicate that, rather than focusing on rewards for motivating students' learning, it is important to focus more on how to facilitate intrinsic motivation, for example, by beginning from the students' perspective to develop more interesting learning activities, to provide more choice, and to ensure

that tasks are optimally challenging (e.g., Cordova & Lepper, 1996; Deci, Schwartz, et al., 1981; Harter, 1974; Reeve, Bolt, & Cai, 1999; Ryan & Grolnick, 1986; Zuckerman, Porac, Lathin, Smith, & Deci, 1978). (p.15)

Niemic and Ryan (2009) prepared an overview of motivation and self determination theory and concluded that:

Classroom practices that support students' satisfaction of autonomy, competence, and relatedness are associated with both greater intrinsic motivation and autonomous types of extrinsic motivation. Strategies for enhancing autonomy include providing choice and meaningful rationales for learning activities, acknowledging students' feelings about those topics, and minimizing pressure and control. Strategies for enhancing competence include providing effectance – relevant, as opposed to norm based evaluative, feedback and optimally challenging tasks. Strategies for enhancing relatedness include conveying warmth, caring, and respect to students. (p. 141)

The work of Pink, and the scholarly work he based his ideas upon, motivate the current study because one wonders why the students would proceed from one stage to the next in the activity. Work by Silvia (2008) indicates that interest, as an emotion, is instilled when situations are perceived by the subject to be both new *and comprehensible*. This insight further motivates the current study; students could potentially have found certain aspects of pendulum motion to be beyond their range of understanding less than

motivating. What personal or social factors could potentially influence the students' actions?

Overview of Cognitive Theories and Motivation: Preparing for the Study

Constructivism, conceptual change, singular plural, and science classroom driven models of learning have been reviewed above to set a context for interpreting the data in the study. Although it was difficult prior to data collection to “make a call” as to what approach to learning theory would be most relevant and valid in relation to the current study, it is important to note, in the literature, the importance of background knowledge, what the students bring to the table, when students approach their work with pendulum motion. And finally, this review serves as a description of the various models for learning and science that the researcher brought to the experience of observing the students in action.

Description of Research Related to the Current Study

This review of research about student questions in an inquiry setting provides a context for the current study. At times, for ease of comparison, an advance or anticipatory look at the related component(s) of the method of the current study will be provided just after the a given study is described. Specific details of the method of the current study are provided in chapter three.

Chin and Brown (2002) did a study on student questions generated by two groups of three eighth graders in science inquiry settings ranging from solubility to melting point investigations. Audio and video tapes were analyzed in conjunction with interviews of

the students and field notes. The researchers classified the questions they encountered into two broad categories; wonderment and basic information. Wonderment questions included those that related to comprehension, prediction, and other factors, and basic information questions related to procedures and facts. The authors found that “wonderment questions comprised only 14% of all questions asked” (2002, p. 532), and observed:

The percentage of wonderment questions relative to the total number of questions was highest (30%) for the activity on the separation of a salt-sand mixture.

Notably, this was the only activity which was open-ended and problem-solving in nature where students were not given step by step instructions on how to carry out the task. (p. 533)

In the current study, the pendulum motion activity took place with few procedural instructions. It was as open-ended, and perhaps even more open ended, than the salt-sand activity above because students were not even be given a task as specific as separating salt from sand. Rather, they were given materials and asked to create their own questions and goals from the start. Therefore the Chin and Brown study is relevant, but not identical to the current study. The current study does not compare types of questions asked in one setting to types posed in another setting.

Keys did a study of grade six students generating questions and plans for open – ended science investigations. Keys (1998) examined the reasoning strategies of students “who had the freedom to generate their own questions for investigation in an everyday classroom setting” (p. 301). Research questions focused on how the children generated

the questions, the characteristics of the questions, important cognitive activities, management of manipulation of variables, and emerging teacher roles. Student projects were “initiated by a teacher-directed exploration activity” (p. 304). The projects took place over roughly 15 hours of instruction. Class videotapes and student written work were reviewed and a coding scheme of fourteen interpretive codes was eventually established” (p. 305). Keys was able to arrive at and support the assertion that “students pursued two main avenues of ideas for questions; varying the teacher directed activity and inventing questions from their own imaginations.” (p. 305). She further noted that “some of the children’s questions led to experimental investigations and some led to descriptive investigations” (p. 306). Keys also developed and supported the assertion that an important cognitive activity was transforming abstract ideas into physical objects and events (p. 307), as well as noting that three different patterns of control of variables in the students’ actions and words were prevalent. (p. 309).

Keys concluded that “The freedom to generate authentic questions fostered students’ creativity by allowing them to pursue topics of real interest to themselves or to build unique variations on teacher activities” (p. 312). The second part of the quote brings to mind the idea of abductive reasoning. In her section on suggestions for future research, Keys notes that “Our understanding of how children respond when asked to pose their own questions and design investigations to answer them is still relatively primitive” (1998, p. 314). This comment is an indicator that the current study could contribute to our knowledge of student questions.

The research done by Keys informs the current study a great deal, and the comment just above serves as motivation. Similar to the work of Chin and Brown (2002), Keys found two main avenues of student questions. And a similar distinction between the work of Keys and the current study can be made; the teacher in the Keys' study initiated the student project with a full demonstration, but again, in the current study, students began their work from step 1, or perhaps step 0.5.

Diaz (2011) authored a dissertation thesis on student questions in an elementary science classroom. Argumentation skills were studied. He initiated his discussion about the motivation for the study by noting:

Science education depends on knowing how to argue for the truth. Several key studies (Driver, Asoko, Leach, Mortimer, and Scott, 1994) have shown that students need to participate, through talking and writing, in thinking and making sense of the scientific events, experiments and explanations to which they are being introduced. (p. 1)

Diaz's 2011 work motivates the current study as this researcher carried perceptions related to Diaz's comment that "Several studies have indicated that children do not think like scientists when confronted with experimental tasks" (p.28).

It was posited that students in the current study, being at the upper end or just slightly beyond the elementary age range might provide a rich source of questions that could be analyzed in relation to how "scientific" their thinking might be.

Diaz developed macro, meso, and micro levels of analysis for the study. For instance he examined "challenges, rebuttals, elaboration on students' questions, claims

and evidence relationships” (p. 50). In the results, he included a chart that mapped these argumentation components against Bloom’s taxonomy levels to probe for depth of student thought and reasoning. In comparison to the current study, this study examines the classroom on a broad level and links teacher interactions with students in a number of settings. The current study is more focused on student to student interactions with teacher interactions being minimized. Diaz used an argumentation model; the current study attempts to use a scientific method models and a variety of other schema for categorization.

Walldren (1971) wrote a dissertation on student questions in problem-solving activities. “The broad concern of this study was to determine whether student initiated questions, asked during problem solving, were useful data for analyzing patterns of inquiry” (p. 42). Walldren modified Suchman’s (1968) model of questions that included verification, experimentation, necessity, and synthesis on one axis and events, objects, conditions and properties on an orthogonal axis. Walldren’s modification included verification, seeking, inference, concluding, and a miscellaneous category called “foil” (p. 66). As student questions were investigated, Walldren and co-workers added reliability to the coding scheme through repeated checking for consistency between researchers after they coded certain student questions. In Walldren’s study, students viewed films of science events and responded; the full classroom sessions were videotaped and analyzed. This differs from the current study in that students were starting from a more beginning inquiry setting in a less structured approach working in small groups. Walldren’s work was an attempt to both refine an instrument for analyzing

student questions and analyze the resulting questions. One of his concluding statements about the questions is as follows:

The investigator as well as the analysts believed that a basic pattern of questioning would emerge from the codings. Very simply stated the expected strategy would have begun with a few Verifying questions that established the problem set. A large number of Seeking questions were expected next. These, it was believed, would have been followed by one or two Inferring questions. After a very few Seeking or Verifying questions a Conclusion was anticipated. This basic syllogism, however, did not emerge. In fact, precise descriptive strategies of student questioning were not actually documented in this limited study. (p. 96)

The fact that Walldren had an anticipated model of student flow of questions, and that evidence for this model was not directly found, informs the current study. For instance, Walldren found that “Concluding questions” occurred in the middle, and not just at the end, of student inquiry sessions.

Walldren also noted:

The logic of instructional agendas— that is, teaching sequences, textbook sequences, and lock-step curricular sequences— may have to be reappraised if learning through inquiring continues to be an educational objective. The teaching logic of these ordered presentations may be somewhat dissonant to the learning logic of students engaged in problem solving. To be more specific, many teaching methodologies may have to be modified or even replaced. In this

teachers should acquire practical methods which facilitate learning rather than methods which control classroom behavior and learning. (p. 99)

This passage is an early precursor to further, later work (D. Dillon, O'Brien, Volkman (2001) that indicated that what happens in the classroom does not always match the models educators carry in their minds about best practice or how students go about their learning. It also served as a valuable motivator for the current study in terms of the potential relatedness (or lack thereof) of a proposed model to what actually would happen in the classroom.

Krajcik et al. (1998) studied the inquiry actions of eight seventh grade students who were members of science classes engaged in project based learning. Through the use of video analysis, classroom observation, and interviews, they were able to track the progress of the students as they worked on major, multi-week projects formed around a driving question provided by the teacher such as “Where does our garbage go?” (p. 318). Teacher pedagogic interventions took place through the project. Krajcik (1998) and his research team were able to observe and classify the student questions during this process through their (researchers) framing questions of:

What were the characteristics of the question? Was it descriptive or experimental? Was it feasible? Was it scientifically worthwhile? How was the question generated? Did students gather and draw on background information, consider alternatives, make predictions? (p. 322)

Descriptive and relational questions were detailed in their results discussion. They noted that some questions stemmed from personal experience as opposed to a desire to

explore scientific phenomenon. The analysis of questions centered around those questions that were of the research driving type at the start of the activity; the full range of questions that students could potentially pose throughout the process of doing inquiry were not reported in this article. All components of student progress in the web of investigation were described – areas such as constructing apparatus and carrying out procedures included a description of what students did, stated, and measured. In a relatively broad assessment of the students' questions they noted that “the students did not have enough experience with inquiry to fashion meaningful questions” and that “we need to learn more about the instructional supports that can help students determine the meaningfulness of their questions” (p. 343).

Good et al. (1987) studied student questions in the classroom in grades K,1,3,6,7,9, and 12. Questions posed by students within “regular” classroom settings were tabulated. After initial pilot sessions that allowed researchers to standardize their coding schemes, nine different categories of student responses were used; Explanation, Information, Clarification, Confirmation, Procedural, Non-Task Curiosity, Diversion, On-Task Attention, Off-Task Attention. The researchers were interested in various socialization factors related to student questions, and for instance, they found that in later grades, low-achieving students asked fewer questions than students at other achieving levels. Of relevance to this study is that the existence of student questions was less related to cognitive models of doing science (in fact science classrooms were not observed) but more related to equity and developmental questions. Investigating the type and number of student questions provided evidence of the amount of “passivity” that

students were displaying. They also provided an important caution (1987), though, for the current study by stating:

We realize that all learning is problematic, and we make no simple assumptions about student questions. For example, students can ask questions to distract from the learning process, to embarrass the teacher, or to hide the fact that they have not read the material or were not paying attention. Students questions could also indicate dependency needs (needs for assurance) or an inability to think clearly and independently. Thus, we do not assume that in classrooms in which students ask more questions, there will be more learning. (p. 184)

It was deemed important in the current study to allow for the fact that there could have been a number of questions that students generate that do not at all relate to the problem they are investigating. Further, this researcher has noted in various ad hoc observations of students in inquiry settings through the years that questions often come as statements. The comment “the bigger the mass the bigger the period” could easily translate to “I wonder if increase in mass will give an increase in period?” In the current study, efforts were made to tease questions out of more declarative comments. There is a fine line, (especially in the case of a pre-adolescent child) between the certainty of a comment and the request for information.

D. Dillon, O’Brien, and Volkman (2001) did an in-depth qualitative study of students working in collaborative groups in a high school biology class. They investigated the reading, writing, and talking of students as they attempted to complete the tasks they were assigned by their teacher. In their analysis of student group dynamics,

they developed an assertion that “The types of writing that small groups engage in are both a function of and a contribution toward the relative social and academic status of students” (p.65). The three categories for writing participation social status generated in their analysis of the data were “Low Social Status Excludes Participation....High Status Gives Participatory Rights..... Group Members are Positioned by Others” (p.65).

An implication of the study is that “the way students position themselves or are positioned by their peers during groupwork, shapes the literacy practices of individuals and of the group” (p. 65). Although specific details of the study will be described in chapter three, it is of value to mention how the above study relates to the method used. In the current study, it was anticipated that students would talk to each other as they posed questions about their investigation of pendulum motion. At eight to ten-minute intervals, they were to *individually* write down their questions. The intent of this component of the research model was in part to afford students the opportunity to step outside of their group dynamic if they wished to write down questions of interest to them. It was certainly not clear that this would mitigate the group effects mentioned by Dillon et al., but it provided multiple sources of “literary data” during one class period of time. It was important to not just assume that the written questions would match the questions stated out loud by members of the group.

Dillon et al. also noted that “we conclude that reading, writing and talking as they occurred on a daily basis in the biology classroom we studied, bear little resemblance to the ideal uses proposed by literacy researchers” (p. 67). In the current study, it was

essential to bear in mind the possibility of contrast between models and practice, and to avoid forcing the questions into predetermined scientific method categories.

Mortimer and Scott (2003) investigated and described the process of doing and talking about school science. They analyzed science classroom interactions over an extended period of time. They developed an analytical framework (2003) that is “based on five linked aspects, which focus on the role of the teacher in making the scientific study available, and in supporting students in making sense of that story” (p.25).

Although the majority of their observations include some component of teacher intervention or leadership as the students experience the scientific story, the authors do analyze student – student discussions. They noted that one student acted like a teacher (p.98) in posing questions that help the group to proceed. It did not appear that her role was assigned; rather she grew into it as part of the group process.

Although Mortimer and Scott’s classroom study was geared more to general student and teacher construction of the scientific story and the transition from more common place vocabulary and understanding to specific use of science concepts, it is interesting to note the different roles taken on by students. Mortimer and Scott’s work indicated that some student questions could be similar to those asked by teachers.

Inhelder and Piaget (1958) studied students of varying ages and reasoning levels and analyzed their efforts in working with pendulum motion. The following classic account described the need to define and control variables:

The variables which, on seeing the apparatus, one might think to be relevant are:
the length of the string, the weight of the object fastened to the string, the height

of the dropping point (= amplitude of the oscillation), and the force of the push given by the subject. Since only the first of these factors is actually relevant, the problem is to isolate it from the other three and to exclude them. Only in this way can the subject explain and vary the frequency and oscillations of the problem. (p. 69).

This is the classic description of the classic problem that asks “What factor(s) affect the period of a pendulum?” Imbedded in the above description is the problem of finding the factor(s).

Inhelder and Piaget detailed the responses of children at different cognitive stages. Fifth graders (perhaps ages 9-11) might be at Piaget’s cognitive stage II (preoperational) or at the beginning of stage III (concrete operational). The authors delineate a substage II-A (one example given of an eight year old student) where a subject can gain information that period and length are inversely related but will not be able to isolate the variables (p.70). In stage II-B (a ten year old example is given) a subject shows progress with serial ordering and the inverse relationship, but there is still a lack of separation of key variables. Substage III-A is then presented (Possible but not Spontaneous Separation of Variables – p. 73) and a twelve year, seven month old child’s efforts at being somewhat more systematic in isolating length as a key variable.

Inhelder and Piaget followed this with an account of a fifteen year old being able to separate the variables and the identification that length is the critical variable in determining the period. In the current study, youngsters were not to be asked to determine what affects the period; they were to be asked to pose questions and follow

these questions up with investigations. No specific attempt was to be made by the researcher to classify the questions in relation to the stages of cognitive development. Nevertheless, knowledge of the stages forms a background for understanding what the students' strengths and limitations might be as they developed their investigation.

Research Method and Methods of Classifying Questions

Introduction

The research of J.T. Dillon (1984), Blonder, Mamlock-Naaman and Hofstein (2007), Dolan and Grady (2010) and von Aufschnaiter, Erduran, Osborne, and Schneider (2008) helped to build a general perspective in developing and evaluating options for data gathering and analysis for this study. The work of Miles and Huberman (1984), Stake (2006) and others helped to form a framework for within site and cross site analyses of student questions.

In preparing for this qualitative inquiry, it was important to describe and acknowledge the background information that this researcher brought to the study while allowing space for the development of conceptual frameworks as the data unfolded and patterns of student questions emerged. Miles and Huberman (1984) noted that “any researcher, no matter how unstructured or inductive, comes to fieldwork with *some* orienting ideas, foci, and tools” (p. 27). These authors also noted that “Analysis during data collection lets the fieldworker cycle back and forth between thinking about the existing data and generating strategies for collecting new — often better quality — data” (p.49). Stake’s (2010) comment cautioned “There is a risk that the plan (of research) will

become a mechanism that interferes with the open and interpretive stance taken by the researcher” (p. 85).

Question Classification and Approaches to Analyzing Inquiry Settings

J.T. Dillon (1984) paraphrased Aristotle's Posterior Analytics inquiry classification (p. 328) by including the key components of existence/affirmation, essence/definition, attribute/description, and cause/explanation. Dillon (p. 330) then elaborates his own classification scheme, which includes first order (properties) second order (comparisons) third order (contingencies) and extra order (other). He included detailed sub categories, and P-Q logical relationships within his classification table. Note the distinction that Dillon's efforts are directed towards research questions while Aristotle's framework is based on the attainment of knowledge in a more general sense.

Dolan and Grady (2010) observed two expert teachers engaged in inquiry instruction in the Partnership for Research and Education in Plants (PREP) program. A case study approach was used; purposeful and convenience sampling (Patton, 2002) was employed. The researchers first identified "best case scenarios" of inquiry teaching by analyzing a number of educational settings and narrowing their study down to the two expert teachers. They observed the inquiry process for a six to eight week period for the two teachers, interviewed the teachers throughout the process and students at the end of the process, and triangulated their findings through mutual discussion and discussion with scientists. They engaged in an iterative process of categorizing responses, and constructed a "Complexity of Scientific Reasoning During Inquiry" (CSRI) matrix. This matrix was used to categorize and describe the types of activities that took place within the inquiry continuum ranging from generating questions to communicating and

defending findings. Reasoning tasks were categorized as least complex, somewhat complex, more complex, and most complex. Dolan and grad found, that in the realm of generating questions, ‘Janet’s students based their questions on their own observations while Bonnie’s students based their decisions on prior knowledge and discussions with a scientist (somewhat complex reasoning)’ (p. 44).

Blonder et al. (2007) did a study of students doing an inquiry activity with gas chromatography. There were pre-inquiry and pre-lab activities such as the study of chromatographic methods. Students were asked to formulate three varied relevant questions, select one for further inquiry that if possible included a link between two variables, formulate a hypothesis, and conduct and analyze and experiment. The researchers assigned three possible levels to the questions; those regarding subject matter, those related to scientific equipment used, and those concerning real life. The authors discovered that 80% of the questions generated were level 1 questions, 14 % of the questions were level 2, and 6 % were level 3.

The review of the above work (J.T. Dillon (1984), Blonder, Mamlock-Naaman and Hofstein (2007), Dolan and Grady (2010) set the stage for the component of the current study where categories for questions were sought. Miles and Huberman’s (1984) perspective that qualitative researchers approach their work with a given mindset that could evolve during the research is also pertinent. The possible anticipated question categories for the current study ranged from Aristotle’s four key categories including essence/definition, to Blonder et al.’s subject matter, apparatus, and real life oriented categories. This researcher approached the observation of the students in the current

study with these categorization schemes as available options, but with the realization that different categorization approaches could be considered more appropriate as the study unfolded.

Pilot and Target Study

Von Aufschnaiter, Erduran, Osborne, and Simon (2008) have developed four areas of abstraction attainment (concrete, abstract static, abstract dynamic, and systemic) in relation to student argumentation. These areas are an example of the levels of attainment that London students who were engaged in argumentation reached with their questions and discourse. These authors developed a coding scheme by first observing a pilot group and working together to cross-reference the categories of questions they observed to refine and standardize the anticipated categories for questions. They then used this coding scheme during the actual study. Other studies (for instance Good et al. (1987)) use this sequence of a pilot coding activity followed by application of the standardized codes that were developed during the main part of the study.

Yin observed “The pilot case study helps investigators to refine their data collection plans with respect to both the content of the data and the procedures to be followed”(1984, p. 74). In the current study, a pilot study of one *class* of students (many cases) was to be undertaken to gain information about the logistics of the study and data collection and analysis techniques.

Interview Techniques

Josselson (2013) provided numerous examples of in-depth interviews in her work on interview techniques. Although the current study employed only a short interview, it

will still be important to, as Josselson described “treat our participants with respect, sensitivity, and tact” (2013, p.13). She further pointed out that “the research relationship is fundamentally a special case of a human relationship, and we have to be thoughtful about the relationship dynamics that are created between us and our participants” (2013, p. 14).

Stake (2010) suggested three main purposes for interviews, which can help the researcher to obtain unique information, collect numerical aggregation, and learn about the “thing” that researchers are unable to directly observe. All three purposes mentioned related to this study. The interview was intended to find out about the perspective for the questions posed by the students. Further, the information that could potentially be gleaned from the interview was intended to be of benefit in determining question categories and patterns. Direct discussion with the student(s) had the potential to reveal insights into what the students were thinking that were not readily apparent in the other sources of data.

Mortimer and Scott (2003) included a note about “Transcribing and translating oral discourse” (pp. 132-133). They outlined hurdles they had to overcome in presenting student discussions as they prepared transcripts. Student questions and comments do not necessarily occur in sequential relation to each other – more random comments and questions could be generated at the same time. Also, students are likely to use hand gestures to add context to their ideas. The transcript, in its sequential form, does not necessarily capture the essence of the dialog, but it does provide helpful information.

Likewise, the list of questions generated in the current study had the potential to be difficult to place in context.

Case and Cross-Case Analysis Techniques

Miles and Huberman (1984) posed two key questions at the outset of their discussion about analyzing qualitative data:

- 1) How can single case researchers build a progressively integrated map of field site phenomena that has *local* causal significance?
- 2) How can data from multiple sites be aligned to make inferential maps containing more *general* causal explanations? (1984, page 132).

Corbin and Strauss (2008) provided guidance for researchers with this comment “The asking of questions is a tool that is useful at every stage of analysis, from the beginning to the final writing. It helps researchers when they are blocked and having difficulty getting started with their analysis” (p. 67).

Stake (2006) described the tension between the particular and the general by stating “Case study issues reflect complex, situated, problematic relationships” (p.10). His observations are often related to case and multi-case studies he and others have done where the single case could be an educational workshop or program. Although the current study has a much more microscopic “case” (the student asking the questions) this tension had the potential to exist.

Stake defined a “quintain” as a collection of related cases that are somehow categorically bound together. He stated (2006) “a cautious qualitative researcher sees the quintain as multiply sequenced, multiply contextual, and functioning coincidentally,

rather than causally determined” (p.13). Stake (2006) further described the “case-quintain dialectic”:

The dialectic works like this.....The Themes originated with people planning to study the Quintain. The findings originated with the people studying the Cases. These are two conceptual orientations, not independent but different. To treat them both as forces for understanding the Quintain, the Analyst keeps them both alive even when he or she is writing the Assertions of the final report. (pp. 39-40)

This researcher acknowledges that the dynamic described above is effectively applied and balanced by a seasoned qualitative researcher. This researcher predicted in advance that as the data in the current study unfolded, finding ways to maintain the information learned about each student’s set of questions, while looking for valuable trends and patterns in the data, would be a difficult challenge. In reviewing the work of Stake, Patton, Corbin and Strauss, and Miles and Huberman, it is evident that there are also a lot of pragmatic efforts that help in this regard, such as making charts, sorting documents, reading and re-reading reports, checking the meaning of given items, and lots of cross referencing between the particular and the general. These pragmatic actions, though, are done with a vision established by the context of the research question(s), research, and a lot of reflection about the key issues being studied.

Krajcik et al. (1998) described their approach at the concluding stage of their analysis for their study of student inquiry in a seventh grade setting as follows:

The third phase of analysis involved comparisons across the cases to determine commonalities and differences in how students engaged in inquiry. Guided by hypotheses that emerged from the cases, data were displayed in tables to enrich ideas and to verify patterns as described in Miles and Huberman (1994) and Yin (1991). Analyses moved through iterative cycles of examining data, generating hypotheses, and searching for confirming or disconfirming evidence for conclusions. (1998, p. 322)

The intended analysis in the current study was to follow a pattern similar to that described by Krajcik above.

Reflexive Nature of the Study

The comments by these authors emphasize concepts central to both the content and methods of this study. From a content standpoint, Corbin and Strauss emphasized the importance of questions *at every stage of analysis*. From a methods standpoint, the main current study research questions about student questions will be in the following section, but as is pointed out in the above quote further low and perhaps larger level questions will emerge throughout the analysis. The reflexive nature of this research is to be noted. These same authors further exemplified (p.65, 2008) the value of questions by citing Blumer's (1969) comments about Darwin's approach to observation:

The naturalist Darwin, according to Blumer, also had his strategies for working with data and for good reason. Blumer (1969), paraphrasing Darwin, states:

Darwin, who is acknowledged as one of the world's greatest naturalistic observers on record, has noted the ease with which observation becomes and remains imprisoned by images. He recommends two ways of helping to break such captivity. One is to ask oneself all kinds of questions about what he is studying, even seemingly ludicrous questions. The posing of such questions helps to sensitize the observer to different and new perspectives. The other recommended procedure is to record all observations that challenge one's working conceptions as well as any observation that is odd and interesting even though its relevance is not immediately clear.” (pp. 41–42)

This passage affords two entry points in relation to the current study. First of all, the students themselves will be going through a process of asking questions. A potential category of questions (those that break the mold or go against the grain of perception) is suggested by Darwin as being of importance. Secondly, Blumer’s portrayal of Darwin’s comments is important to the process of doing the study; the researcher for the current study had to be aware that some data could reveal surprises that do not fit into the anticipated patterns.

Miscellaneous Observations

J.T. Dillon (1988) is quoted by Chin and Brown (2002) in their literature review that sets the stage for their study of student questions. They are describing reasons why students may not ask questions:

Dillon (1988) has also suggested that students may also fear negative reactions from classmates and the teacher, and that systematic conditions (structures of the

school relations between adults and students socialization into institutional and situational authority roles) may also inhibit student questioning. (p. 522)

This perception is one of the reasons that the current study provided students the opportunity to write their questions down during eight-minute intervals throughout the inquiry activity. Although the writing down of questions might have slowed thinking down in some cases, it also afforded students the opportunity to voice their questions without concern for how their questions would be viewed by others.

Stake (2010) used a description of a librarian developing a plan for research to illustrate helpful approaches to doing qualitative research. Within this context, he introduced the idea of a “minicase” (pp. 83-85) that can be delved into more deeply to help shed light on the research question. In the current study, the minicase concept was indeed applied, through the use of video – recording, to gain a more magnified view of what was happening with the development of student questions within one group in a class.

Patton (2002) described sixteen different types of purposeful sampling (pp. 230-246). The qualitative researcher may choose to select cases that provide special insights into the research questions that have been posed. Some of the strategies available to a qualitative researcher include using extreme or deviant case sampling, typical case sampling, critical case sampling, analyzing confirming or disconfirming cases, and opportunistic sampling.

To summarize the above studies, researchers generally used various techniques to observe students engaged in the inquiry process and to categorize their actions,

comments, and questions. Different approaches to analyzing and categorizing questions and reasoning tasks were developed based on the unique needs of the study at hand.

Although it is difficult to characterize these studies with one statement, it is fair to say that the categories of “basic”, or beginning questions, “procedural”, or questions about equipment, etc., and ‘wonderment”, questions that we testable or could lead to testable questions were worth anticipating in the current study, while heeding the caution that other categories could emerge during the study.

It was deemed by this researcher to be essential to exercise care and insight with respect to ethical and relational issues. There is a reflexive nature to this study, since research questions are developed and investigated about student questions in science. In the next chapter, the design of the study will be discussed. The review of qualitative research literature places this into context; it is not just the details of the plan of the study, but also the background of knowledge, and potential options for interpreting the actions and questions of the students, that help to frame the study and understand what happened.

Overall Summary of Literature Review

For this study, a key research question relates to the patterns, or categories, that develop for the questions that students pose while engaged in an inquiry activity on pendulum motion. A natural outgrowth of this attempt to find patterns is the question “How does what the students do and ask compare to models of doing science?”

This review of the literature is an attempt to gain preparedness that will assist with looking at both sides of the above comparative equation, as well as in making the comparison. In looking at the right side of this “equation”, various models for doing

science, including that developed by NGSS (2013), Lawson (2003a), linear models presented in middle school science textbooks including an “IScience” text published by American Museum of Natural History (2012) and the Berkeley community of science model published by the University of California Museum of Paleontology (2013) have been presented and analyzed. These models range from more “linear” approaches to science that include starting with a puzzling observation (Lawson 2003a) and devising hypotheses and tests, to more cyclical, community based models such as that proposed in the Berkeley model.

For the left hand side of the “equation”, literature on cognitive theory, group learning, methods of classifying questions, and research on student questions have been reviewed. The cognitive theory section presents an overview that ranges from constructivism to models such as conceptual change that place more emphasis on background knowledge. Also, the “peeling away of layers” of understanding on a progressive basis as discussed by Roth (2006) was considered. Importantly, Deci and Ryan’ Self-Determination theory was introduced as a potential framework for interpreting why students would inquire or act in the current study. This review of cognitive theory served to form a general background of preparedness for observing the student actions in the inquiry activity in the current study in an informed manner. Similarly, since students in the current study worked in groups, with the implication that analysis of group dynamics would help to frame the interpretations, group learning literature has been reviewed. Findings relevant to the current study (Dillon, O’Brien, and Volkman, 2001) include the realization that student actions do not always match an

educator's model for how they go about developing their understanding and completing their task, and that many actions of students in a group relate to establishing, or are a consequence of, social status. The literature on classification of student questions, and on research of students generating questions in inquiry settings, affords the insight that questions have often been grouped in broad categories ranging from "basic" to "wonderment" (Chin and Brown, 2002) with "procedural" (Blonder et al, 2007) question categories also noted. Importantly, Keys (1998) emphasized the finding that more "wondering" than "basic" types of questions were posed when students were doing more open ended activities.

Therefore, from the review of the literature, a variety of options exist on both sides of the "student question patterns" compared to "methods of science" equation. To gain a foothold on the right side of the equation, Lawson's (2003a) hypothetico-predictive model was selected. The model includes clear guideposts for each stage of the scientific pathway, and is coupled with Lawson's development of how students learn science. Finley and Pocovi's (2000) work that compared traditionally cited steps in the scientific method to more realistic and current interpretations is referenced as an approach to using a given traditional model as a framework for further development and comparison.

Multiple entry points for the left side of the equation, patterns in student actions and questions, were available. The initial intent was to select JT Dillon's distillation (1984) of Aristotle's four types of questions and to also consider how the questions fit

into the categories or patterns suggested by Lawson's hypothetico-predictive model.

Allowance was made for the development of other schemes of classification.

For the "comparing" aspect of the research, methods of doing qualitative inquiry have been presented. The idea that various models that fit the data, (analogous to "multiple working hypotheses") as well as consequent refinements in the collection of the data, can unfold (Miles and Huberman, 1984) as the research takes place is essential to the study. In order for the "unfolding" and evolving to occur, some cognitive scaffolding, as developed from the various components of the review of the literature, was deemed to be of benefit.

Chapter 3: Design and Method of the Study

This study is about the questions fifth-grade students posed during an inquiry activity on pendulum motion. The students worked in groups of average size of four over a 45-minute period in a relatively unstructured setting. A goal of the study was to record, analyze, and categorize the questions posed by these students to gain insight into student thinking and actions during the activity. Lawson's hypothetico-predictive model of how science can be done served as one of the key models for framing this analysis.

Research Questions

The research questions are listed below to serve as context for the method.

1. What questions do the students ask?
2. What types of patterns exist (if any) in the questions that are posed?
3. In what way do the questions provide evidence of abductive reasoning?

Description of Qualitative Inquiry Components

In the current study, the following definitions are adopted.

Unit of Analysis – A question posed by a student

Case – the set of questions posed by all students in their group of four during a 45-minute period of inquiry activity and 20-minute follow-up interview, within the context of their activity.

Case for Deep Investigation – One group of four students, with advance parent permission, was video-recorded. During the post hoc interview they were provided with an opportunity for further investigative work.

Group – The set of all six lab groups that did the 45-minute activity.

Quintain – The set of all questions, nested by four-student lab group, that were posed during the activity and interview.

Context – The questions posed were interpreted within the context of the lab activities that took place.

Description of Research Method

Pre-Pilot Activities

The design of the study was presented to the University of Minnesota Institutional Review Board, which approved the research.

On a preliminary basis, a pair of adults analyzed pendulum motion for 30 minutes and filled out question sheets every five minutes. This researcher engaged in a similar activity. This in turn was followed by activity of a similar nature by family members. These pre-pilot activities served to inform the pilot study.

Pilot Study

At a private school in the midwest, a group of 30 fourth, fifth, and sixth graders engaged in a 45-minute pendulum motion activity under the direction of the researcher, with the permission of the school, and observed by three teachers in the school. The school was chosen purposefully on the basis of availability, positive lines of communication, and a shared understanding of the research task.

The students worked in groups of three or four. The groups were separated by a distance of about six feet. Each group had a ringstand, clamp, protractor, meter stick, string, stopwatch, paper clip, and washers. With this equipment, they were able to build a set up for pendulum motion that allowed for the variance and measurement of pendulum

length, mass of pendulum bob, amplitude, period, etc. The researcher read off a set of instructions (similar to appendix C) that indicated to the students that they would ask questions and design an experiment of their choice. The students were not given specific information about vocabulary or concepts of pendulum motion. Safety guidelines were emphasized.

The students recorded their questions every five minutes by writing for one minute on separate (different colored) sheets of 8 ½" x 11" paper as directed by the researcher. Each five-minute interval had a different color of paper so that questions could be linked to the time interval in which they were generated. The students recorded data, information, observations, etc. on a separate, 11" x 17" sheet of paper. For example, at the twelve-minute mark, the students took one minute to write down their questions on a yellow sheet of paper. This was their third set of questions since they had already written questions down at the zero and six-minute marks. The students worked on pendulum motion for 45 minutes. At the end of this activity, 22 of the students returned to other classrooms for regular instruction. To have a group of workable size for discussion, eight students remained for continued work on pendulum motion and discussion with the researcher. The discussion helped the researcher gain insights into what the students were thinking. It also provided information as to how to improve the method of the study.

Post-Pilot / Pre-Target Activities

The pilot activity was analyzed by the researcher with an eye towards improving data collection techniques in the target study that would follow. The chart below

summarizes the observations made in the target study and corresponding adaptations to the research technique.

Table 1: Analysis of Pilot Study

Observation/comment	Refinement (if applicable) or comment
The students did indeed investigate pendulum motion, they asked and recorded questions, and the questions were varied and extensive enough to do an analysis	Good!
Often, students had difficulty transitioning from their data sheets to their question sheets and back. The act of writing questions on a separate sheet interrupted the flow. It was not easy to see how student questions related to student actions, even though the prompt “record in one sentence what you were doing “ was given.	Each student will be given a large data sheet. They can use that to record numbers, procedures, charts, etc. At the start, students will be given a blue pen to record their questions and data. At roughly eight-minute intervals, students will be given a pen of a different color (e.g. green, then red, etc. Over a 40-minute period, pen color will be switched 5 times, to gain a rough time frame of what was happening and what questions were asked. Students will be prompted at ten-minute intervals to write down the questions they have on their answer data sheet. This entire large piece of paper (12” x 20”) will serve as the set of questions and actions.
Students often asked a question, got data, but measured poorly and were able to confirm their predictions even if not valid. For instance, they were able to support the claim that adding washers to the end of the pendulum changed the period, even though this is not valid. Students showed varying levels of skill in ascertaining how their data answered their question.	Students will be gently reminded to measure carefully. Nonetheless, this is likely to remain an issue. It may be a developmental attribute/ combined with prior knowledge issue that intervention will change only so much. Measurement skills and concepts will vary greatly.
Students would ask a question that was really not testable, but then proceed to test a testable question.	Writing ability is different than questioning ability. The use of audio recorders will be important.
The questions fell into Dillon’s synopsis of Aristotle’s question categories more readily than Lawson’s h-p method. But there was often a trend to skip along Lawson’s method, get some quick confirmation, then ask a why question, and move to a new experiment (see attached question grid with numerical sequence). This building process is almost	No major impact on research method – except this could inform an interview question. Note: the question “do students often follow approaches to qualitative inquiry in doing a science experiment?” is interesting for follow up study.

more similar to many different qualitative inquiry techniques, including grounded theory?	
We did not proceed with the audio recording due to lack of processing of parent consent forms.	A post pilot – pre target small trial will be done to refine audio technique.
The process by which a question was chosen in the first few minutes was fascinating.	This provides motivation for the current study and has implications for future studies.
It is indeed the case that many questions are asked by students that are not addressed.	Interesting ... no impact on method.
The addition of the prompt on the question sheets (what did you do in the last interval) yielded good information, with many well written sentences, but at times writing this one sentence was all that a student accomplished during the writing time.	The use of the large sheet with the data/actions in different colors will reduce the need for the prompt to write down the recent actions so students can focus on writing questions.
The differentiation of “what questions do you have about your experiment?” and “what questions do you have about pendulums?” provided a valuable distinction – student questions were more focused than in pre pilot.	This concept will be applied in the target study too.
Some writing is difficult to decipher.	The practice of using the interview to clarify what was written is indeed of value.
It was interesting to see some relational questions.	“Relational “ is one of JT Dillon’s question sub categories. This is a heads up that this could be an important question category.
In managing the groups to enhance engagement, students were asked to rotate roles during the activity – e.g. more than one person measure.	It is not realistic to consider effect of group role on type of question.

To summarize, the use of the colored pen system (new color pen every 8 to 10 minutes) in combination with large data sheet (all students record their own data) became components to be pre-piloted before the target study. This pre-pilot, with just a few students, was used to ensure that the audio recording system worked effectively also. In preparation for the target study, in communication with the principal of the school where the target study would take place, this researcher put a spotlight on the need to have parent consent forms sent out. This included parent permission forms for the video group and student assent forms for all students participating. These permission forms

were important because the audio-recording was essential in capturing all of the questions that students would verbalize during the process. It was encouraging to see that the basic plan for getting the questions worked. The researcher added a question about abductive reasoning to the post hoc interview.

Follow up to Pilot: Small Group Activity

After the pilot analysis, a small group of students was selected (consent from neighborhood parents) to do a brief trial of the colored pen system and the audio-recording system. This session revealed that the colored pen system was feasible and effective. The audio-recording process was found to be workable as well.

Target Study

A parochial school in the midwest was purposefully selected to do the target study. Positive communication lines, school and class size, and accessibility were key factors in this selection. Contact with parents took place well in advance. At the request of the researcher and using the appropriate forms (Appendix A&B) the school obtained parent consent for video and assent for participation and audio-taping. Pre-research meetings with the principal and the teachers took place. The classroom space was selected and observed. *Virtus* training, a general required preparation for doing work with children in the school, was undertaken by the researcher.

The students were seated in small groups around tables that had the same equipment as the pilot study. There were four groups of four, one group of three, and one group of five as deemed appropriate by the host teacher through a process of student self-selection and teacher management consistent with typical classroom practice.

Each student was given a large data collection sheet and a blue pen. All groups were audio-recorded and one group was video-recorded. Instructions (Appendix C) were read aloud by the researcher, with similar guidelines as in the pilot. At intervals of approximately eight minutes, each student was given a pen of a new color for recording questions and information. The pen color served as a time indicator. The students proceeded to do this unstructured pendulum motion activity for about 45 minutes. At the end of the 45 minutes, the students were asked by the researcher to write down what they had learned in the activity.

Students were given goggles and were reminded periodically throughout the period to keep wearing them. The researcher reinforced other safety cautions such as not over-swinging the pendulum bob. There was a minimum of intervention by the researcher or host teacher (present throughout the activity) in terms of group dynamics; but questions were answered about the general nature of the activity e.g. “Yes, please write this down” or “You are to design your own experiment”.

Since there were two sections of fifth grade at this school, this activity was repeated for the second class in similar fashion; the first class, though, was the target study.

The next day, each group was interviewed and audio-recorded for 20 minutes. The same pendulum and measurement equipment was available for reference during the interviews. This second session allowed the researcher to review what was written, look for evidence of abductive reasoning, trace the flow of activity during the investigation, and gain further information about student questions and thinking with an eye towards

the role of the questions in the investigative process and how they could be categorized.

A brief discussion between the researcher and the host teacher took place about perceptions and observations of the host teacher to serve as perspective.

Student data sheets, audio and video-recordings were then available for analysis as described in chapter 4.

Method of Analysis

The video and audio-tapes were repeatedly reviewed. Transcripts of the tapes were prepared. This allowed the researcher to tell the story (Appendix F) of each group with observations and perceptions followed by general comments about the questions. Post-it notes containing each question posed were organized and reorganized in various iterations in an effort to search for and find appropriate schema for classification. The question patterns across groups of students were also compared. An attempt was made to sort the questions by role in the scientific method and by type of question in relation to J.T. Dillon's distillation of Aristotle's categories (1984).

Triangulation took place with respect to the written questions, audio-recordings of the questions, researcher observations of the student progress during the activity, host teacher comments, and interview statements. These analyses took place and were followed by further iterations of attempts to place the questions in context, patterns, and categories. The methods of Miles and Huberman (1984), Stake (2010), and Yin (1984) on cross-case analysis were referenced often during this research.

Chapter 4: Analysis and Results

Analysis

The analysis begins with a numerical overview of the questions that were asked. This is followed by a review of overall trends in the questions within the context of the laboratory activities. Note that a full description of each group's questions and actions is included in appendix F. A sample transcription (group 2) is included in Appendix H. A complete list of all questions (both written and spoken) can be found in Appendix G. A sample of the student question/data sheet is reproduced in appendix I. Finally, in this chapter, assertions will be made about the questions posed, supported by evidence from the data. For context, the research questions are included here:

1. What questions do the students ask?
2. What types of patterns exist (if any) in the questions that are posed?
3. In what way do the questions provide evidence of abductive reasoning?

A variety of attempts to categorize the questions was undertaken. Ultimately, two methods of categorization proved feasible. The first of these related to the purpose served by the question in relation to the progress of the student investigation as viewed through a "scientific method" lens. The second set of categories relates to Deci and Ryan's self-determination theory (2000). The tables that follow provide an illustration of the types of questions that students posed.

Description of Table 2: Number of Questions of Various Types with Respect to the Progress of the Investigation

The chart below (Table 2) provides an overall description of the numbers of questions in each category. The first column is the group number, and the second column is the number of students in the group. The third column provides the total number of questions written down by all members of the group on the papers provided. The next column includes the number of oral questions, followed by the total number of questions. For instance, in group one, 31 written questions and 60 oral questions were posed by the four group members, for a total of 91 questions. Written questions were deemed to be those written comments that were followed by a question mark. In a few cases, where it seemed clear that a question was posed and a question mark was inadvertently omitted, the comment was deemed to be a question. The following processes were used to determine the number of oral questions. The transcript for each group was read by this researcher. The audio recording for the group was listened to on a repeated basis, using the stop/rewind/playback buttons. Comments that had voice inflection at the end of the sentence were deemed to be questions. Furthermore, if there was doubt in terms of the inflection, the definition “a question is a request for information” was used to identify a comment as a question. In a few cases, it was difficult to determine whether or not a comment was a question. For instance, if a student said “It’s gonna stop in 45 seconds”, with a slight inflection at the end, it was difficult to ascertain if a question had been posed. This ambiguity was generally resolved by taking such comments not to be questions. However, if student 1 said “It’s gonna stop in 45 seconds”, and student 2 said

“(You think) it’s gonna stop in 45 seconds?” then student 2’s comment was taken to be a question.

A description of the definitions of basic, mechanistic, functional, procedural, and comparative questions is provided below:

Basic – Questions that seek information about the general nature of a pendulum, such as

“What is a pendulum?”

Mechanistic – Questions that inquire into the mechanism of the pendulum, not just the data results, such as “Why does the pendulum take longer to stop swinging if it has more weight on it?” The student is interested in what it is about the pendulum and the laws of nature that produce the observations made.

Functional – The student is inquiring into the relationship between two variables. An example of this is “Does the time to stop depend on the number of washers added to the paper clip?”

Procedural – Questions about how to do something, such as how to measure the period, length, or time to come to rest for a pendulum. These questions could also relate to equipment, such as “How do you use the stopwatch?”

Comparative – Questions that relate the data to a prediction or question. An example would be “Does our data show that more weight added to the end increases the period?”

Note that the categories of questions in the last five columns are neither exhaustive nor exclusive. In other words, the sum of the questions in these last five groups does not necessarily match the total number of questions. Typically, some of the questions in each group were not classified within these five categories; or they fell more

readily into motivational categories as shown in table 3 which will be described in the following pages.

Table 2: Number and Type of Questions per Group.

Group #	# of students in group	# of written questions	# of oral questions	Total # questions
1	4	31	60	91
2	4	17	50	67
3	3	6	40	46
4	4	14	25	39
5	4	10	38	48
6	5	25	35	60
Totals	24	103	248	351

Group #	# of basic Questions	# of mechanistic questions	# of Functional or data relationship questions $y=f(x)$	# of procedural, measurement questions	# of questions comparing data to the question
1	28	4	11	36	1
2	15	4	5	26	0
3	2	2	8	22	4
4	11	0	6	20	0
5	8	3	7	30	1
6	42	1	3	16	1
Totals	106	14	40	150	7

Description of Table 3: Classification of Questions by Motivation Category

Deci and Ryan have developed self-determination theory in various publications. (Deci, Schwartz, Scheinman, and Ryan, 1981; Deci and Ryan, 2000; Deci, Koestner and Ryan, 2001). They identify autonomy, competence, and relatedness as three key motivators. Pink (2009) has elaborated on these in his book *Drive*. When the researcher of the current study reviewed the student questions, it became evident that the three categories developed by Deci and Ryan provided interesting and informative categories into which the questions could be sorted. Although a question could be viewed as a

request to obtain information, it could also be viewed as an attempt to meet a need. The researcher of this study reviewed the questions within the context of the group's actions and attempted to classify the questions according to the need that was being addressed. Note that this does not imply that the need was met. In the case of autonomy, this researcher added the component "authority boundary." An example of a question in this category is "What are we supposed to do?" which, over time, was ultimately followed by the realization that the students were not required by authority to do a specific experiment, although there were authoritative guidelines on safety, etc. Some students may have gained the awareness that they were the ones responsible for posing the investigation question as a result of this process.

An example of a question that is in the relatedness category is "Would you like to use the stopwatch now?" as students attempt to be fair and to connect with each other. A competence question could be "How do you measure the time?" which might then be followed by a statement that they had just figured out how to do this. Questions could often serve as an attempt to meet more than one type of motivational need. In forming the table, questions were classified within each of the three categories. If it was very clear that a question fit a given category, a "strong" designation was given. If it was only somewhat apparent that the question was an attempt to meet a need, "weak" was used.

Table 3: Classification of Questions by Type of Motivation

Group #	Social relationship (Strong)	Social relationship (Weak)	Autonomy (Strong)	Autonomy (Weak)	Authority Boundary (Strong)	Authority Boundary (Weak)	Competence (Strong)	Competence (Weak)
1	11	37	1	1	1	4	7	64
2	16	16	1	1	4	3	3	44
3	18	17	0	2	1	3	7	20
4	2	13	1	1	4	4	3	26
5	6	28	3	0	0	0	0	37
6	2	30	0	0	0	1	1	48
Totals	55	141	6	5	10	15	21	239

Discussion of Table 4: Variables and Questions

Table 4 is a compilation of the questions in relation to the flow of student actions through their experiment and the methods they used. Much of the table relates to the actions and flow of the experiment in addition to the questions that were posed. This is to provide context for interpretation. The main research question is stated in the right hand column, followed in parentheses by the time at which the question was posed. The second part of the table then follows. This includes information about confounding variables , experimental controls, and data analysis.

Table 4: Variables and Questions Part 1

Group #	Main Topic	Variables Manipulated	Variables Measured	Main or Ultimate Question(s) (time)
1	Damping -Energy Loss	Mass (# of washers)	Mass, time to stop oscillating	How does the number of washers attached to the clip affect the time for the pendulum to come to a complete stop? (8-15 minutes) At end – How many angles (planes of oscillation) does a pendulum have?
2	Period as function of mass	Mass (# of washers)	Mass, then -number of swings before stopping - time for one swing - # of swings “laps” in one minute	How does the # of washers attached to the clip affect -the time for one swing? (8 minutes) - the # of swings in one minute (18 minutes)?
3	Damping	Mass (# of washers)	Mass varied, time to stop was predicted and measured	Which student will be the best at predicting the time needed for a pendulum to come to rest for a given number of washers attached to the clip? (5-15 minutes)
4	Period vs Mass	Mass (# of washers)	Mass varied, time for 5 swings measured	Does the time for 5 swings depend on the mass? (midway)
5	Damping	Mass (# of washers)	Mass, time to stop	-How long can it swing? (at beginning) - How many swings to stop? - Will putting more weights on the end of the pendulum make it stop in more time? (Various questions posed throughout)
6	Damping (precession at end)	Mass (# of washers)	Mass, time to stop. (At end the angle was considered)	Will more washers cause it to take more time to stop? (only partially articulated near beginning) And at the end “will the # of washers affect the angles it swings at? (midway through lab)

Table 4 Part 2

Group #	Confounding Variables Identified	Confounding Variables Intentionally Controlled	Data Examined in Light of Question	Valid Result Obtained
1	1 student identified amplitude but was unable to convince group of relevance – no other variables identified	No (but by default length stayed the same)	Partially – cursory look	Yes – it is indeed the case that due to drag effects, more washers leads to more time to stop
2	No	No (but by default length stayed the same) Failure to keep amplitude constant resulted in data that was more extreme in difference than what it should have been	Quickly without detail	In light of data yes but in comparison to accepted theory their result was far more extreme than what one would expect – they should have gotten a much smaller difference in period than what they obtained
3	No	No – but length stayed the same by default	Yes – to see who won (who was the best at predicting)	Not applicable, but at a secondary level, their data supported the idea that more washers led to more time to come to a stop
4	No	No – but length stayed the same by default	Patterns noted and discussed during data collection	No
5	Amplitude (near end of data collection)	No – but length kept the same by default	Not at end – but partially on a trend basis during data collection	Result not clearly stated by students – but data and a few comments indicate a correct result
6	No	No, but length stayed the same by default	Partially	Yes but the students did not really state their result

Table 5: Time of Research Question With Respect to Action

Group #	Description of timing of main research question	Activities that immediately preceded the question
1	Measurement procedures started first, then the question was posed, then data collection continued	Recognizing that more washers can be placed on the clip, Asking how long it takes to stop (without respect to # of washers)
2	Measurement procedures for the first research question took place first, then data collection continued. However, the second main research question was posed prior to data collection	A student asked "If we have two will it go quicker than one?" Discovery of use of stopwatch and how to time a swing
3	Measurement procedures started first, then the question was posed, then data collection continued. The competitive "Who is best at predicting" question came early, and questions about trends in the data took place later.	After various competitive outcomes and arguments, students asked one student why he was successful at guessing the time to stop. The response was "If you add more weights it takes longer"
4	Measurement procedures started first, then the question was posed, then data collection continued.	Individual timings of swings, the addition of weights, and the question "how fast does it go?"
5	Right at the start, one student posed a question in writing that was similar to the ultimate research question. Measurement procedures started first as a group, then the question was posed and shared by all group members, then data collection continued. It is not easy to determine when the question was actually agreed upon by all members of the group.	Due to the difficulty of identifying when the main question was posed, it is hard to identify the precursors.
6	Measurement procedures started first, then the question was posed (this developed gradually over a long span of time), then data collection continued. A second question was asked about planes of oscillation late in the activity.	Various informal data collection procedures took place. The observation of different planes of oscillation was followed by the question about this same topic.

Discussion of Table 5: Time of Research Question With Respect to Action

Table 5 is a description of the timing of the posing of the main research question within the context of other experiment actions. Also included is a brief description of the activities that immediately preceded the posing of the question.

Overall Trends in the Questions and Actions

These trends are based on the analysis that took place. They will be summarized in assertions that will follow.

1. The groups of students in this study tended to choose the phenomenon of damping to investigate. The questions associated with this were “How many swings until the pendulum stops?” and roughly “How does the number of washers attached to the paper clip affect the amount of time for the pendulum to stop?”
2. The groups of students in this study identified number of washers added to the paper clip and time to stop as key variables in the experiment. The variables of length and amplitude were far less likely to be identified, changed, or controlled. Length remained unchanged by default through the experiment. It appears that students did not see length as a variable to be changed or controlled. This was the case even after prompting during the post hoc interview.
3. Students initiated their process with basic questions such as “How does a pendulum work? These questions were prevalent through the first 8 to 10 minutes of the study. In some cases, a basic measurement question such as “How long can it go?” or “Can we time it?” was posed.

4. The groups of students in this study typically initiated the active part of their investigation process by noting that a given measurement device could be used or that some materials (e.g. washers” could be manipulated. The implicit question “Can I attain competence with this measurement device or equipment?” was a further motivator for activity. After this, midway through the experience (e.g. after 8 to 15 minutes) the students might pose a relational question such as “How does the amount of washers affect the time for the pendulum to stop?”
5. The immediate precursors to the posing of this question varied from group to group. In some cases, the recognition that a variable existed or could be measured led to a question about the variable. In one case, competitive social interactions led to the articulation of a relationship – it is difficult to know what was in the students’ minds before they asked the questions they asked. It was not always evident when a question “crossed over” from being vaguely formed in a student’s mind to being explicitly stated. The puzzling observation that a pendulum could swing in different planes led to a potential research question in group 6.
6. The groups (of course) could only control a variable if they know it existed. Control of variables was not evident in this laboratory experience. This may be because students did not identify any other relevant variables, or it could be that they did not realize that they should control these variables. In some cases, towards the end, students recognized that amplitude could be a variable.

7. Students were not likely to carefully scrutinize their data in light of their question. Various forms of more philosophical argumentation would take place. Most typically, a cursory look at the data in light of the question was followed by the idea that another experiment would be interesting to do.
8. As data was collected (not after) students were interested in whether or not it fit a pattern. Instead of full scale repetitions of the entire process or revision of the question or hypothesis, or revision of the data collection technique, they would recollect data for a given value to double check it. Or another student would say “That didn’t fit – let me try it”.
9. To summarize these trends, the following process took place.
 - Step 1: Ask basic questions, such as “What is a pendulum and how does it swing?” These might include basic measurement questions such as “How long can it go?”
 - Step 2: Identify materials of interest and measurement devices of interest
 - Step 3: Attain competence with some component of the activity, such as measurement of time of swing, etc.
 - Step 4: “Practice” making measurements about, for instance time to stop, with a vaguely shared and partially understood implicit question about time and mass (washers) added.

Step 5: State a more relational question that grows out of the activity that is already taking place.

Step 6: Collect data – during this phase, the generic question “Can (may) I be the one that measures (gain competence with measuring) the next trial?” is important.

Step 7: At this point, there is little in depth comparison of how the data relates to the question. There is a general assumption that the evidence is sufficient to verify the proposed relationship. It is then far more interesting to move on to a new related or unrelated question.

This is not “what should be done” or “the scientific method”. It is what tended to actually happen in these groups.

10. There were occasions in many groups where a student would pose a relational or testable question that might be considered to be of interest by an adult educator. But, the group of four students could ignore this question in light of more basic questions. In other words, the group was not cognitively or socially ready for this student’s questions.

11. The following categorization systems for classifying questions, in order of fit, are listed below:

- a) Building on Deci and Ryan’s work on motivation, the categories of competence, autonomy, and personal relationships form three slots that work

well with the questions posed by these students. Many questions were easily and readily classified into one of these three categories, and essentially almost all others could be considered to meet a motivational need to some extent.

- b) Generally speaking, the flow of questions (note distinction between questions here and actions in # 8 above) was as follows:
- i) Basic questions
 - ii) Questions about what the authority intends for them to do, what the boundary is between the student and the authority, and what the student or group has the autonomy to do. (Authority/Autonomy)
 - iii) Questions about how to measure something or questions related to the discovery that a stopwatch or washers could be used. (Competence)
 - iv) The “discovery” (not really a “puzzling observation”) that the equipment was implicitly linked to a variable that could be studied, e.g. time or mass (Competence).
 - v) A relational question (sometimes in the form of a claim with an implicit question mark at the end).
 - vi) A question that was related to the discovery that there may be additional variables (only posed by some groups).
 - vii) Questions (along the data collection path) about whether the data fits the vaguely formed hypothesis.
 - viii) Questions about what new experiment could be done.

Assertions

Five assertions will be presented. The first level building blocks for these assertions are the audio and video recordings of the students in action. Further building blocks include the post hoc interview of each group, the preparation of transcripts and data sheets (such as question vs. time sheets for each group), and attempts to sort the questions by components of the Lawson's hypothetico-predictive model of reasoning, Deci and Ryan's self-determination theory, Dillon's distillation of Aristotle's question types, and pendulum variables and properties investigated. The story of each group was developed (see appendix K) through a series of observations, perceptions, and attempts to classify the questions. Insights and trends were then developed, so that these assertions could be formed. The assertions relate to insights and trends that are most solidly supported by evidence.

The assertions will be supported by the data and illustrated by excerpts from transcripts and group experience accounts. The full group experience accounts, and one example of the transcripts, can be found in the appendix.

Assertion Number 1

Students' questions often emerged as the students attempted to meet the motivational needs, as described by Deci and Ryan's self-determination theory of competence, autonomy, and relatedness as they traveled along a pathway that led them to ask a question of interest and follow through to gain relevant information.

Related Evidence and Support

This researcher reviewed the questions and made multiple iterative attempts to find categories that were best suited to classifying the questions. After attempting to classify the questions into categories related to Lawson's hypothetico-predictive method, Dillon's distillation of Aristotle's four key question types, and other classification schemes, the "progressively integrated map (p. 134)" as described by Miles and Huberman (1984) that emerged was related to the work of Deci and Ryan. It became apparent to this researcher that students were attempting to meet key needs as they posed their questions. Examples are as follows:

Throughout the process of the activity, the three boys in group three were essentially competing and cooperating with each other to see who was the best at determining the amount of time needed for the pendulum to stop. At roughly the 26-minute mark, one student in the group asked "Guys, what's your hypothesis (prediction) for this one gonna be?" This student was asking the other two to predict how long it would take for the pendulum to stop swinging for a given number of washers. The need for "competence" was a motivator for this and many other questions. Throughout this process there were a variety of relatedness questions such as "ready?", "What exact second is it at?" and "Are you ready to hold that up?" as the students worked together. The students' data chart included a gold, silver, and bronze winner for best predictor. A student in group 1 asked, at roughly the four-minute mark, "Are we supposed to put weight on it and swing it back and forth?" This was an example, also seen in other groups, of beginning attempts to clarify the boundary between authority intent and

student action. “Should we record our questions?” is another example of a question of this type.

A student in group 2, at the roughly nine-minute mark, asked “Why do we need the stopwatch?” This was followed by questions, interactions, and comments that helped to meet the need for being competent in using the stopwatch. The attainment of competence in using this measuring device was important to the group members. At times, it was difficult for this researcher to neatly classify a given question into one of the three needs – but it was very consistently evident that a need, or a blend of needs, was being addressed when a question was posed.

One might ask “What need is being met by a student who poses a key testable question for the group? For example, when a student in group 6 asked “Does weight have an effect on which direction it swings?, were they attempting to meet a need for relatedness, competence, or autonomy? A look at some of the work by Deci and Ryan (2000) could help to frame this analysis. The authors note

...it is adaptive, for children to play, but they do not play to feel competent. Similarly, curiosity based exploration, openness to the sensory experiences of nature, and assimilation of values extant in one’s social milieu – all natural activities – require the nutriments of basic need satisfaction to operate optimally, but these activities are not necessarily (indeed they may seldom be) consciously intended to satisfy these basic needs. (p. 230)

Therefore, it could be viewed that student questions are, at an underlying level, providing some of the scaffolding for the process of doing inquiry, but these motivations may perhaps need to be further accompanied by the building blocks of curiosity and other factors. Note that this researcher has classified the majority of the questions within “weak” categories using Self-Determination Theory. Perhaps the reason that the classification is weak is that these are only underlying motivators that are to be accompanied by other factors as students demonstrate the intrinsic motivation to complete their activity.

Perhaps the work of Silvia (2008) on interest as an emotion applies to this situation. As student efforts are sustained by the meeting of their competence, autonomy, and relatedness needs, they could reach a point where they become interested in some key question – such as (group 1) “How long can it swing with a certain amount of weight?” or (group 2) “Does it swing more when more washers are added?”. Both of these questions were posed at roughly the eight-minute mark. Silvia (2008) noted “if people appraise an event as new and as comprehensible, then they will find it interesting” (p. 58). The terms *novelty-complexity* and *coping-potential* were used, respectively, to denote these factors that can affect interest.

It could be argued that students asked a variety of questions that helped them to meet one or more of the three self-determination needs as they progressed along a pathway of interest. Furthermore, the attainment of competence with, say, measurement techniques could set the stage for the posing of an interesting, research based question. A question could occur to students once their competence with measurement and awareness

of various pendulum phenomena had allowed them to reach a point where a question was novel but deemed by the students to be not overly daunting – within the sweet spot of Silvia’s two appraisal conceptualization of interest. The key question that was studied was posed, for each group, well after initial measurement processes were underway, which could indicate that various needs were being met prior to the posing of the main research question.

Assertion Number 2

The students’ questions followed a time sequence that related to attempts to meet needs and a general attempt to use their senses and reasoning skills to gain information.

Further Articulation of Assertion 2 and Related Evidence

The questions did not follow the time sequence that would be predicted by Lawson’s hypothetico-predictive method or similar models of the process of doing science. Rather, the meeting of motivational needs was intertwined with the experimentation/learning method that followed the pattern of first asking basic questions, then posing questions that helped to define the boundary between authority intent and student action, followed by questions about how to measure an attribute of the pendulum, followed by an unspecified but generally shared understanding of a variable or variables to be measured. This in turn was typically followed in most cases, by a question (also at times vaguely formed) that related two variables. As the data was collected, there was ongoing intuitive evaluation of how each data point related to the generally shared

prediction or question. This in turn was typically followed by questions about what new experiment could be done.

The chart below shows this contrast.

Table 6: Comparing Lawson’s Hypothetico-Predictive Model and the Student**Actions**

Lawson’s Hypothetico – Predictive Method (Lawson, 2003, p. 197).	Asserted Method Followed by the Students in this Study
1. Making an initial puzzling observation.	First asking basic questions, in order to gain a basic level of understanding of the phenomena. This goes hand in hand with the students gaining familiarity with the pendulum and measuring equipment.
	Then posing questions that helped to define the boundary between authority intent and student action, *
2. Raising a causal question.	Followed by questions about how to measure an attribute of the pendulum, which in turn is at times followed by specific one time measurement questions such as “How long for one swing?”
3. Using analogical reasoning to generate one or more probable hypotheses. Analogical transfer, or analogical reasoning, involves borrowing ideas that have been found to “work” in one or more past related contexts and using them as possible solutions/hypotheses/guesses in the present context.	Followed by an unspecified but generally shared understanding of a variable or variables to be measured. This in turn was typically followed by, in most cases, a question (also at times vaguely formed) that related two variables.
4. Supposing for the sake of argument and test, that the hypothesis under consideration is correct. This supposition is necessary so that a test can be imagined with relevant condition(s) that along with the hypothesis allow the generation of one or more predictions.	“Research” activity was already initiated in the absence of a hypothesis or question
5. Carrying out the imagined test. The test must be performed/conducted so that its	(Data collection is underway before hypothesis is formed.)

predicted result can be compared with the observed result of the actual test.	
6. Comparing predicted and observed results.....A good match means that the hypothesis is supported, but not proven, while a poor match means that something is wrong with the hypothesis, the test, or with both.....	As the data was collected, there was ongoing intuitive evaluation of how each data point related to the generally shared prediction or question. Post hoc evaluations rarely took place or if they did so were superficial in nature.
7. Recycling the procedure. The procedure must be recycled until a hypothesis is generated, tested, and supported on one or more tests.	This in turn was typically followed by questions about what new experiment could be done.

* note – it is possible that some students may have made puzzling observations – but there were no or very few oral or written questions or comments about puzzling observations.

One way to interpret the above chart would be to say that the students were engaged in pre-inquiry, or pre-research activities that ultimately blended into an approach that has some scientific aspects. Another interpretation would be that fifth graders experience a different self/objective reality boundary than mature scientists. And again, Deci and Ryan’s self determination comes to the fore here – students, for instance, first meet the competence need of knowing how to measure before they formulate a question for research.

Excerpts from the descriptions of the experiences of the groups can further illustrate the flow of questions. The members of group 3, for instance, first asked questions such as “What are we going to do?” interspersed with “What are we supposed to do?” This was followed by questions and comments such as “You’re not supposed to use your (wrist) watch” and “How do you use the stopwatch”. “Supposed to’s” became less prevalent as they proceeded with the activity. They met social relatedness and competence needs

through engaging in a competition to see who could best predict the time for the pendulum to stop. It was only after learning how to measure the time to stop by using the stopwatch and through further “competition” that, halfway through the activity, they began asking each other why they were predicting certain amounts of time for it to stop.

The progression of questions posed in group 1 also illustrates this sequence. Initially, questions like “What is a pendulum?” and “What is this?” were posed. Also, early on, was the question “Are we supposed to put weight on it and swing it back and forth?” This was then followed by “How long is the time to stop swinging?” as students demonstrated interest in the fact that the time to stop could be measured and that they could in fact measure it with the stopwatch. At the first written question writing interval, which occurred at roughly the eight-minute mark, some students were still at the “How long can it swing?” or “What is it used for?” stage while others were beginning to consider relationships such as “When you have more washers (does the time get bigger)?” Parentheses indicate the most likely conclusion of unclear question. Generally speaking, at this stage, there was a vague formation of a variable relationship question without a specific question; data collection proceeded. Progress was not linear – there were other competence questions at the 10 to 15-minute mark relating to what a centimeter was, whether or not they should measure length, and whether they should count or time swings. This dialog took place alongside, and in part related to, the process of gaining competence with measurement processes. As measuring skills became more automated, more relationship questions and comments surfaced such as “The washer(s) is (are) because when it gets more it swings longer (takes more time to stop)”. (Student

question not grammatically correct) Trials with various numbers of washers took place and data revealed that the previous statement was indeed valid – but there were no real formal, in depth analyses or steps connected with this realization. Rather, a more tacit feel for the relationship was developed, and students asked “Should we do another experiment?”

Group 2 members had, at one portion of the activity, the following sequence:

one to two-minute mark – How long does it take? (How long does it take the pendulum to do one full swing)

four-minute mark – Will 2 go quicker than 1? (will the pendulum swing more quickly with 2 washers on the clip than with one washer on the clip)

seven to eight-minute mark – How do you use this? (stopwatch)

eight-minute mark – Does it swing more when more washers are added?

(“translation” not completely unambiguous)

Ca. 15-minute mark – What we figured out was that adding a washer makes it go slower

Ca. 15.5-minute mark – Ok – so that was experiment 1?

Ca. 16-minute mark – How many times will it swing in one minute?

Note the less than specific formulation of key research questions coupled with a progression of gaining confidence with measurement techniques. Note also that questions about specific measurements, as opposed to relationships, were also present.

This group did reach a point where they asked a second question – “How many times will it swing in one minute?” which represents a refinement in measurement technique.

Important footnote: The Lawson model has provided a valuable frame of reference that helped to interpret the flow of student questions, even though this flow did not align directly with the model. Further comments about this distinction will be found in chapter five.

Assertion Number 3

Most significantly in the above sequence, questions about procedures of measuring and learning how to measure, and the actual conducting of measurements, preceded the formulation and sharing of a testable question. The key, relational, testable question occurred midway through the data collection process, (stated either directly or implicitly shared) well after such questions as “How do I measure this?” and “What is the time for one swing with one washer?”

Evidence for Assertion 3

As shown in table 5, this was consistently true in the case of each and every group. Action preceded the posing of the key research question, and when this question was posed, it did not emerge in a clear, precise fashion, but rather, in a generally shared implicit sense.

Assertion Number 4

Procedural questions about “how to measure” were the most prevalent in the study. These questions were important to the students.

Evidence for Assertion 4

150 procedural, measurement questions were posed by the students. This is 43% of the total of 351 questions posed by all students in the study, and about 13% more than the number of basic questions, which was then next most prevalent category. “How do you use the stopwatch?”, “How many times did the pendulum swing?”, and “How much time did it take?” are examples of the questions frequently posed by students. As mentioned earlier in the assertions, perhaps there is a strong competence need that fuels these questions.

Assertion Number 5

The phenomenon of damping (as exemplified by the time for the pendulum to come to a stop) was the pendulum attribute that was by far of most interest to these students.

Evidence for Assertion 5

Damping was the main research topic for groups 1, 3, 5, and 6. Groups 2 and 4 explored the relationship between period and mass. Note that since the pendula are not ideal, this is less of a clear null result than one might at first anticipate. Therefore, four of the six groups dealt specifically with damping, and all six groups essentially investigated the effect of friction. Typically (groups 1, 5, and 6) the relationship between the number of washers added to the end of the pendulum and the time needed for the pendulum to

come to a complete stop was investigated. Group 3 “competed” to predict the time needed for the pendulum to stop. A member of this group, near the end of the activity, did ask “Why?” it slowed down and why more washers affected the time to do this.

Note (and this was never articulated by any students in the study) that the addition of washers decreases the air resistance to mass ratio, which in turn increases the ratio of gravitational force to friction, which reduces the overall effect of drag and damping, with the consequence that more washers added to the end does increase the overall amount of time needed for the pendulum to stop. This investigator confirmed this effect using the equipment used in the study.

The classic, Piagetian relationship between length and period did not emerge during the main activity in the study. During the post hoc interviews, this researcher provided opportunities (with various degrees of “nudging”) for the students to investigate this relationship. Even in this setting, students tended to remain more interested in damping. It is possible that students did not initially perceive that it was possible to change the length of the string, even though this could have been readily achieved by wrapping the string around the horizontal support clamp.

The concepts of energy, damping, perpetual motion, and gravity, though not clearly defined in the students’ minds, were possibly being explored in parallel to the attainment of the damping data.

Assertions That Were Not Formed

The research questions posed at the start of this study related to possible frameworks of categorization of the questions in the study. The use of abductive

reasoning was also to be investigated. Lawson's framework for the method of doing science, J.T. Dillon's distillation of Aristotle's four key question types, and other frameworks were used in attempts at classification. Deci and Ryan's self-determination theory was found to be useful in categorizing the questions. With respect to Lawson's method, it became clear early on in the analysis of the questions that the students were doing "their version" of science inquiry, and that this version did not closely match Lawson's method. This study does not, in any way, provide clear insights as to how science is done by expert scientists. Lawson's framework, though, did provide a valuable backboard against which the reality of the inquiry (or perhaps pre-inquiry) process of the students of this study can be reflected. The chart in the above analysis (assertion 2) compares and contrasts Lawson's hypothetico-predictive method with this researcher's perception of what actually happened in the study. Dillon's synopsis of research questions, again, proved to be too much about research and not enough about what these students actually did. Aristotle's existence/affirmation, essence/definition, attribute/description, and cause/explanation was a potentially useful scheme for categorization. When this researcher attempted to sort the students' questions into these categories, a great number of the questions posed by the students remained unclassified. Students, however, asked a very tiny number of causal questions that would serve the purpose of explaining why a given phenomenon occurred. There was a great number of procedural "how to measure" questions that, if the Aristotle framework were to be applied, could be construed as "how do we go about learning about the essence or attributes of the pendulum?" One would have to take the conceptual leap that asking

about how to measure something means “ascertaining existence” in order to place these measurement questions into the existence category. It could be hypothesized, also, that students at the fifth grade level are not sufficiently removed from their subject matter in order to objectively inquire into a phenomenon in a way that would result in questions that fit the categories. Perhaps, if it were possible to tease out the questions that remain after self determination needs and separation from authority takes place, it would be possible to sort the questions into the Aristotle categories. This is beyond the scope of the current study. Having said this, the fact that some students may have progressed from inquiring into the basic nature of the pendulum to inquiring into its essence gives evidence that some aspects of Aristotle’s framework could be relevant to student inquiry settings. Complete, consistent evidence for this was not found.

Overview of Research Questions

The analyses above address the research questions, “What questions do the students ask?” and “What types of patterns exist (if any) in the questions that are posed?” The assertions above provide some insights into the answers to these two questions. However, the question about abductive reasoning was difficult to research. Although the students were asked about the source of their questions during the interviews, responses revealed that a more sophisticated approach to collecting this information would be helpful. At this retrospective point, the research question “What was the source of the main research question for each group?” or “What needs to happen before a good question is asked?” seem more appropriate than the original research question about abductive reasoning. When the above analyses are viewed in light of these questions, it

might be possible to assert that students needed to have a practical feel for the equipment, measuring techniques, and basic aspects of pendulum motion before posing their research question. The Aha! spark that is the moment that the research question was posed had two features:

1. It typically did not occur right at the start of the activity.
2. It was typically more amorphous and less specific as it grew out of the shared experience of working with the pendulum and measuring equipment.

The discussion about the source of the questions will be taken up further in the next chapter.

Numerical Anecdote

351 oral and written questions were posed by 24 students over an approximately 40-minute time span. This means, on average, for this activity, for a given student, a question was asked once every three minutes. For a given group, therefore, more than one question per minute was posed. Note that this does not include the questions formulated in the student's mind that were not expressed in oral or written form.

Chapter 5: Findings, Implications and Limitations of the Research

Discussion of Results

Self-Determination Theory and Need-Based Questions

An important finding of this study, for this group of students, is that they posed their main research questions midway through their inquiry activity. This is certainly not surprising! To add substance to the above observation, it is important to first look at what happened before the student “research questions” were posed. It is suggested that students needed to first meet competence, autonomy, and social relationship needs before attaining the cognitive and emotional readiness to ask a testable question. It was found that it was possible to classify the questions posed according to the needs developed in Deci and Ryan’s self-determination theory.

Sequence of Student Actions and Questions

The second finding, or assertion, related to the typical sequence that took place in the student actions and questions in this activity. Students initiated their work with basic questions about the nature of the pendulum. They then asked questions that related to gaining competence with the equipment (mainly how the pendulum swung or how to add washers to the clip) and measurement devices (mainly the stopwatch). This helped them to identify that a variable or variables existed. At roughly the same time, while gaining further skill at measuring that variable or variables, the gradual development of a research question was typically evident for all six groups. This was in turn followed by ongoing data collection and intuitive data evaluation. The students were apt to ask about a new possible experiment towards the end of their data collection process.

A look at recent research by Loukomies, Pnevmatikos, et al. (2013) is relevant here. The authors conducted a study of a teaching sequence that was designed to enhance lower secondary student motivation towards science. The learning modules and student interview and survey responses were analyzed in relation to self-determination theory to gain insights into adolescents' psychological needs. The authors developed "embodied conjectures" in their design of the study and of the educational program in the study, which included visits to local businesses and factories. These conjectures are summarized in successive paragraphs that describe needs for competence, relatedness and autonomy, as well as the need for curiosity and interest. The following passages illustrate these themes:

"The inquiry tasks completed prior to the visit provide yet another opportunity for the students to act autonomously."

"Support for students' feeling of social relatedness was included in the designed teaching sequence through the selection of collaborative learning activities."

"Support for students' feeling of competence was included in the designed teaching sequence through the selection of constructive evaluation methods."

"The students are responsible for their own questions."

"Interest research suggests means of sparking students' situational interest, namely the novelty and complexity of a certain phenomenon (Silvia, 2008).

Students' interest is supported through offering them novel experiences, including the chance to see multi-faceted, even surprising phenomena in an authentic context." (pp. 2522-2523)

In the results section of their article, the authors note, in describing one student's actions and responses, that "this student increased her self-determination and her need for autonomy from her teachers' authority, competence and relatedness by decreasing her levels of anxiety and diminishing the avoidance of failure that no longer had any meaning" (p.2529). In describing the experiences of other students in the program, the authors discuss the importance of autonomy, competence, and relatedness. They do so within the context of the development of scales they developed for motivation types such as external, introjected, identified, and intrinsic. The authors worked together to develop categories for student responses to interview and survey questions. After noting possible shortcomings of the study, which include its short range nature, the authors described the importance of different motivational profiles or orientations per student. The motivational orientations per student result from different degrees of satisfaction of the three basic psychological needs. They also noted that "what our participants stressed in the interview is that they found aspects in the designed teaching sequence that fulfilled their psychological needs." (p. 2535).

Other research about self-determination theory in relation to the learning of science suggests that teacher actions that support autonomy can lead to student attainment of autonomy and competence (Lavigne, Mallerand, and Miquelon, 2007). Smith, Deemer, Thoman, and Zazworsky (2013) studied student motivation in college science research and wrote:

Self-determination theory (SDT; Deci and Ryan, 1985, 2000) represents an appropriate framework from which to study students' scientific motivations

because it accounts for both the internally-derived needs for autonomy, competence, and relatedness, as well as external contingencies that are thought to motivate behavior. (p.497)

So, it is fair to say that there has been a recent emergence of research that attempts to relate self-determination theory to science learning and scientific inquiry. After all, if students are presented with pendulum equipment and a stopwatch and asked to investigate its motion, one could ask, fundamentally, “What motivational factors will guide their actions in the absence of extrinsic factors such as grading systems and specific teacher direction?” Deci and Ryan’s self-determination theory, combined with Silvia’s work on curiosity as an emotion (2008) could serve as important guideposts in answering these questions.

If one looks at the student efforts through a different, more practical lens, it could be argued that students asked the questions that they could ask given what they knew. Perhaps, for instance, they did not ask about the relationship between the length of the pendulum and its period of oscillation because they had not sufficiently understood that the length could be varied and that changing this length could affect the period. The amount of prior knowledge could also be an important factor, and as mentioned above, this was not directly obtained. The insights in the work by Finley and Pocovi (2000) about the importance of prior knowledge are among many (Posner and Gertzog, 1982a; Scott, Asoko, and Driver, 1991) research efforts about the importance of prior knowledge. Roschelle (1995), synthesized the work of many researchers in an article entitled Learning in Interactive Environments: Prior Knowledge and New Experience.

Of specific relevance is that his work is presented within the framework of the Institute for Inquiry website for the Exploratorium in San Francisco. Even within this context, he emphasized the importance of background knowledge.

Key Finding

Therefore, in reviewing relevant literature and reflecting on the analysis of the current study, it is possible to suggest that student questions could be meeting two purposes in the time interval before they pose a key testable question. First of all, they may be meeting the needs of competence, autonomy, and relatedness. Secondly, they may be developing and sharing background knowledge that relates to the pendulum. These two activities could perhaps set the stage for interest and curiosity to take place; there will be some optimal point in the process where some phenomenon is of interest. The students will gain positive results from implicit appraisals of novelty and comprehensibility, and will be able to proceed with a question of interest.

Further Comments

If one were to go further out on an inferential limb based on what the data could suggest about these fifth-graders' questions, it is possible to view the pendulum as more of a baseball bat than an object of study. As the fifth-grade student gains competence with "swinging the bat" as part of his or her own actions, it then becomes possible to do other things; many students "interact" with the pendulum for a while before really considering it an object of study.

Secondly, one can relate the findings to the "combined result in varying proportions" (p. 93) that Chamberlin (1890) discussed when he described the method of

multiple working hypotheses. Chamberlin also noted that “the true explanation is therefore necessarily complex” (p. 93). In the current study, a key factor that played into the interpretation of the student questions and actions turned out to be self-determination theory. Yet the story of the student questions and actions also includes the selection of their study topic (damping), the prevalence of procedural questions, background knowledge, and the overall flow of questions that partially relate to, but substantially differ from, Lawson’s hypothetico-predictive model.

Procedural Questions

A third key assertion in this study is that procedural questions were the most prevalent. This finding is consistent with a conclusion by Crawford et al. in their 1999 study (already mentioned in chapter 2) that “student dialogue centered on the procedural aspects of the activity when completing teacher -designed activities” (p 710).

Although the distinction between the phrase “teacher designed” and the fact that the current study was relatively unstructured should be made, it is still noteworthy that this finding is a general match with an assertion in the current study. From a practical standpoint, it seems to be the case that students are apt to ask many “how do you do this?” questions as they work through the pragmatic, concrete aspects of their activity. The fact that a large number of procedural questions were posed is also consistent with the overall theme of the assertions. The following is an attempt to distill these assertions into a core theme.

Students posed procedural and other questions as an attempt to meet competence needs, particularly in the areas of measurement and manipulation of the pendulum. They also asked basic questions and acted on these to attempt to gain a baseline of competence and background information that allowed them to reach a point where some pendulum phenomenon was deemed measurable and understandable, yet novel enough to be interesting.

Damping

From a pendulum content standpoint, the assertion that students were fascinated most by the damping effect of a pendulum and the time it took the pendulum to come to rest is strongly supported by the evidence. Less clear is why this was the case. One possible reason for the students' propensity for investigating damping is that this was a readily measurable effect. Measuring the time to stop could have been perceived by the students to be feasible and workable. There could have been a group effect where one group noted the actions of another.

An interpretation, though, that yields a rich pathway for further study and application is that the students were interested in key, core questions about energy, friction, and perpetual motion. Their investigations tied into big, usually unstated questions such as "Is perpetual motion possible?", "Where does energy come from and go?" and "What is the force (gravity?) that propels the pendulum?"

Another interpretation of the popularity of the stopping time research question is that the students were able to make an assumption that made sense to them based on their experience; the pendulum would come to rest eventually, just like everything else in their realm of experience. This assumption might have been more appealing to the students than the "every swing takes the same time" assumption that assists the formulation and investigation of period versus length questions.

Implications for Further Research

Research on curiosity and motivation theory as specifically applied to science inquiry settings has the potential to advance the field of science education in a positive direction. More detailed, sophisticated coding schemes that include a framework for determining whether a given question can be sorted into a self-determination category (competence, motivation, relatedness) could be a part of a study where student questions are analyzed. Although the current study provides some evidence within its own limited setting that key questions are posed after some critical needs are met, a more detailed, structured study with this idea posed as a research question at the front end could provide valuable results.

As for the “curiosity” component, it could be of benefit to expand upon Silvia’s work on curiosity within a science specific setting at the ten to 15 year old age level. Interviews, assisted by Silvia’s curiosity as an emotion paradigm, could be conducted after a student inquiry setting with an eye towards just what produced the Aha! moment during the inquiry setting. This investigator attempted to analyze the data to locate and describe the immediate precursors to the posing of a testable question. No clear pattern of immediate precursors was identified. A range of actions and questions prior to the posing of the research questions took place.

Having said this, it would also be of benefit to investigate whether the Aha! moment is more of an aha interval, spread out over time as a question or connection surfaces progressively through the members of a group. The data in the current study suggests that

for the 24 fifth graders in the classroom, the Aha! moment was not an instant but more of an interval, especially when the group process was taken into account.

Consideration could be given to research about how much students know about friction, and at what level of development that attainment of friction concepts represents. Piaget and Inhelder's work, along with further developments in the field of constructivism, has provided insights into the progress children make along the concrete to formal pathway of knowing and thinking. At what stage of this process can students learn about friction effectively? This is an important concept, because knowledge of friction is important as we learn to discard it when we progress to more ideal situations. Newton's Laws are not always readily learned (White, 1983) by students; the idea of inertia is difficult to grasp in light of the awareness that most things in our environment come to rest instead of continuing on in constant motion.

Implications for Educational Program Development and Approaches to Teaching Inquiry Activities

More intermediate level (4th, 5th, 6th grade) educational activities that allow students to explore friction, the science concept that separates the real from the ideal in many physical science phenomena, are needed. Students may be more likely to study what is of interest to them in the real world as opposed to idealized concepts. The inherent, underlying principles of energy and conservation are explored through the analysis of friction. If students, for instance, are to ultimately explore the period of a pendulum as a function of its length, their engagement in the activity, and connected fundamental

understanding of what is happening, could be enhanced through the attainment of more knowledge about friction. The phrase “let’s consider an ideal, frictionless pendulum” takes on much more meaning if you know what friction is. Further, consideration of this ideal may be in any case difficult for many fifth graders.

In the research activity, students were naturally drawn to the phenomenon of damping. Educational activities that allow students to generate data and explore ideas about damping and energy dissipation could be of value. Although the level of generalization from this study is low, it might be valuable to conduct further studies about student interest in damping so that appropriate activities could be developed. The current study affords insights that suggest that these activities could be playing directly into a natural area of student interest. For instance, an activity for fifth or sixth graders similar to the activity in this study, but with specific follow up teaching about the nature of friction, would be of value.

Educators should be aware that students will meet motivational needs in their approach to doing science. Blending the meeting of motivational needs with approaches to doing science could be an effective way to help students to be engaged in inquiry activities. Intentional reflection and planning in relation to student needs could benefit instruction. Teachers could, for instance, prepare a chart on what motivational needs are being met by various aspects of a lesson or inquiry activity. Deci and Ryan’s self-determination theory could provide a frame of reference for this; the parts of a lesson that help students to attain social relatedness, competence, and autonomy needs could be intentionally identified.

Awareness of the activities that precede the posing of a testable question could be of benefit in planning inquiry instruction. The process of providing introductory practical activities, followed by an interval of discussion about questions, could possibly facilitate inquiry instruction. It is often the case that inquiry activities, more structured laboratory activities, and other science activities begin with a question. Indeed, students are likely to approach their lesson with questions in mind. But these questions are likely to be introductory and basic in nature. It is more probable that, after gaining familiarity with the equipment, competence with measurement, and insight into the nature of the phenomenon, that students are likely to come to a place where they can ask a testable research question. Even at this point, it might be formulated in less than testable terms. Student understanding of the nature of the variables they are testing may become more sophisticated over time. Often, science education specialists encourage their teachers in training to allow their students to become familiar with equipment and phenomena to develop the insights necessary to proceed with inquiry. However, the practical realities of the actual teaching environment in schools, combined with the prevalence of educational materials that introduce lab activities with a question, make it less likely that these pre-inquiry activities will take place. The development of inquiry activities that intentionally spotlight the importance of pre-inquiry, “need meeting” opportunities prior to the posing of a question would facilitate authentic, meaningful experiences for students.

Many intermediate or middle school level science textbooks offer introductory comments or pages about the nature of science. The science process is often said to be

initiated by a puzzling observation or a question. Further, many packaged activities include a question at the front end of the activity. It could be argued that a very important first step for young people engaging in science inquiry is to become familiar with the equipment. This in turn could be followed by development of measurement competence. The maxim “If you can measure it, you might ask about it” could be well worth bearing in mind.

Generally speaking, a key first step could be immersion in the field of study, or more specifically, in the field of play that students will be involved in. Just gaining a general feel for the phenomenon to be studied could be of value.

As teachers in training learn the craft of helping young people successfully engage in science inquiry, it could be of great value for one part of their training to include just watching a group of students work on an inquiry project or task for 45 minutes or more. This practical, authentic activity would allow for reflection about what really happens when students engage in inquiry tasks.

Practical Tips for Teachers Designing Inquiry Lessons

For this researcher, one approach to synthesizing the key findings of the study is to develop a “how to” list for designing inquiry activities. This “how to” list is based on the review of the literature and the findings of the study (which are acknowledged to be just one overall point in the field of qualitative research on inquiry).

1. Provide students with the opportunity for choice at the start of inquiry.
2. Allow for student formulation of the key research question throughout the course of the activity – not just at the beginning.

3. Be aware, in the planning and execution of the lesson, that students may pose many procedural questions as well as questions that seek to meet needs for autonomy, competence, and relatedness.
4. Be aware that as students work on inquiry activities, what actually happens may not match the oft referenced linear model for doing science; be cautious about forcing this model on the students. Keep the general aim of facilitating the process of using one's senses and reasoning skills to learn about the natural world at the forefront.
5. Curiosity, or puzzlement, about a phenomenon, as a precursor to asking a testable question, could occur when the phenomenon appears suitably novel, but the procedures and concepts related to learning about the phenomenon are within the range of background knowledge, measurement skills, and overall competence of the inquirer.
6. Know that phenomena that interest young people might be more practical, real, or concrete than idealized functional relationships.

Limitations of the Study

The findings of this study pertain specifically to the experiences of the six groups of fifth graders at this school. The students were not randomly chosen. The research conditions were not carefully controlled. This study is a detailed account of the questions posed by these students in this setting. It is difficult to generalize the findings in this study to other educational settings. If a similar study were done with fifth graders that had experienced more direct instruction about pendulum motion with the consequent increase

in background knowledge, the results could have differed considerably from the current study.

In this study, pre-pilot activities took place, followed by pilot and post-pilot studies that helped to enhance the research techniques, resolve logistical issues, and refine the approach to collecting data. These activities, combined with the target study, adviser and committee interactions, and reflection upon various approaches to categorizing questions, helped this researcher to code the questions. It should be acknowledged though, that no partner coders were available for this study. This could have added precision to the classification of questions. Having acknowledged this, though, only broad assertions are made in the study. Detailed comparisons of types of questions are not presented.

The data for this study includes video tapes, audio tapes, and written records of the student questions. No in-depth probing techniques for what the students were thinking took place. Although the 20-minute post hoc interviews afforded a glimpse in to student thinking beyond what was written or recorded, it is very likely that some of the questions that students thought about without saying out loud or writing them down are not at all recorded or noticed – and these questions could be relevant to the study. In some studies, various forms of teacher or researcher intervention are used to facilitate student actions and researcher awareness of what the students are thinking. The lack of intervention in the current study had the positive impact of allowing a realistic flow of student thought and action, but some interesting discoveries might have been possible if student thinking was probed at various stages. Finally, within this realm, the “probing”

was approximated by having the students write their questions down at roughly eight-minute intervals. The intervention versus flow spectrum fell in the direction of “interruption” in the case of asking students to pause and write down their questions. This may have influenced the direction of their research. The written comments approach, though, did provide students the chance to voice their own thoughts without group influence.

Students did not take a pre-test about pendulum motion. It was ascertained through researcher/classroom teacher discussion that the students had not had specific instruction about pendulum motion. Teachers did indicate that students had participated in science inquiry activities with varying degrees of structure. Specific, detailed knowledge about what the students knew about pendulum motion and the nature of scientific inquiry was not obtained at the start of the study. It is possible that this information could have been helpful in interpreting the results.

Finally, it should be noted that this study is about student questions first and foremost. It is beyond the scope of the study to derive conclusions about whether or not the results support a given paradigm of cognitive theory, such as constructivism, or a given description of a method for doing science.

Summary

This was a study about the questions posed by six groups of fifth grade students investigating pendulum motion. Questions pertaining to procedures (measurement and otherwise) were the most prevalent. Research questions tended to be about damping and the time needed for a pendulum to come to rest as a function of the mass added to the end of the pendulum. It was found that self determination theory could be a useful paradigm for categorizing the student questions; students sought to meet competence, autonomy, and social relatedness needs. Students typically formulated their research questions during the eight to 18-minute mark of this forty-minute activity, after having first spent some time gaining familiarity with the equipment and gaining competence with measurement techniques.

The sequence of student questions and actions was placed against the background of Lawson's hypothetico-predictive model as a method for describing and understanding these students' actions and questions. The sequence for this study, or "actual student approach to doing their version of science" – using their senses and reasoning skills to understand the world – is as follows:

1. Ask basic questions to gain insights into what a pendulum is.
2. a) Gain familiarity and competence with the measuring equipment.
b) Define the boundary between perceived authority and intent and actual student freedom and agency to carry out the investigation

3. a) Ask procedural questions about how to use the pendulum and measure its actions.
b) Ask specific one time “How long for one swing” questions for practice measurements.
4. a) Generate vague but generally shared understanding of the variable or variables to be measured.
b) Form a question that relates to the variables identified.
- 2-5. a) The research is already underway from step 2 onwards and develops as the question is refined (not after).
b) Data collection is an ongoing, fluid process.
6. There is an ongoing intuitive evaluation of how each data point supports and then further shapes the hypothesis or question. (There is little post hoc, formal comparison of how the data as a whole connects to the question).
7. Ideas for a new study are generated. (“Now let’s do this”).

The above list could be considered a baseline of student approaches to reasoning.

Helping these students to progress to more detailed scientific thinking (Mortimer and Scott, 2003) could perhaps best start with the awareness of the starting place for student thinking.

The 45-minute activity could, to a great extent, be considered a pre-inquiry activity. The activity took place, for the most part, without teacher intervention and without specific instructions about what aspects were to be studied. For this group of students, the study afforded some valuable insights into what they did, what questions

they posed, and what discussions they had at the very start of the inquiry process in an unstructured setting.

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Appendices

Appendix A

Parental Consent Form
Research on Student Questions in Science

Dear Parent or Guardian,

22 February 2014

Your child is invited to participate in a study of student questions in science. The study will take place during one class period and one five minute follow up interview session at _____ school. The purpose of this letter is to inform you about what will happen and to ask for your consent as a parent/guardian.

The study is about the types of questions students ask when they take part in a science activity in school. Students will use basic science equipment during a class period. As the activity takes place, the students will write down the questions they have. The activity session will be audio taped. Sometime within a week after the activity, students will be interviewed for about five minutes by me about their experience.

The class activity has minimal safety concerns. However, general lab safety procedures will be emphasized and reviewed at the start of the activity. Participation in the study is voluntary. If your student chooses to not participate, they will read their science book during the study. If, during the study, a student chooses to stop participating, that is allowed. There is no negative consequence, in terms of grade or assessment, for choosing to not participate in the study. The teacher has indicated that he/she will be supportive of student choice to participate or not participate.

If, during the study, it is deemed best by the classroom teacher or researcher for a student to stop participating, they will be removed without your consent from the study and they will be asked to read their textbook.

Your student's name will not be used when data from this study is published. Every effort will be made to keep information confidential and protect it from disclosure. Students will be asked to not write their names on the sheets they use to record their questions. The audio tapes will not be published. The tapes will be used by the researcher to clarify when students asked various questions.

Information about me (the researcher) is included on the back of this sheet. Advisor and University of Minnesota information is also included. You are welcome to contact me, my advisor, or the college if you have questions or comments. I ask that you if you consent to having your student participate in the study that has been described, you sign both copies of this form, return one to me and keep one copy for your records.

Permission for Student to Participate in Research:

As parent or legal guardian, I authorize _____ (child's name) to become a participant in the research study described in this letter.

Child's date of birth:

Parent or Legal Guardian Signature: _____ Date: _____

Contact Information

Researcher Name and Contact Information:

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Appendix B
Child's Assent Form

Dear student,

22 February 2014

I am trying to learn about student questions in science. In a few weeks, you will be asked if you want to take part in an activity in science class. It is up to you to decide whether or not you want to do this.

If you take part in the activity, you will be part of a group of four students that will be given some science equipment. The science equipment is very safe and easy to use but like any day in science class you will want to be careful when you use the equipment. It will be the job of the group to ask questions about the equipment and then see what they can learn about what the equipment does. You will write down some questions and turn them in to me during the activity. As you go through the activity, you might be able to answer the questions you have, or maybe not. Either of these results is ok.

After the activity, your group and I will have a quick 5 minute discussion to discuss what you did during the activity.

A tape recorder will be used to record what you say during the activity and discussion. The recordings will help me to learn about when you ask questions during the science activity and what the questions are like.

I am going to then analyze your questions. This will help me to learn more about good ways to learn science. Your names will not be made known to anyone else during or after this activity. If I publish my research, I will not include your name in any part of what I write. The audiotapes will be stored and not used again.

Thank you for thinking about being involved in this study. If you choose to not do the study, you will read your science book during the class period and there is no impact on your grade or what your teacher thinks of you. Mr. Jones will completely understand either way.

You can ask Mr. Jones or me any questions you would like to before or during the activity. Signing here means that you have read this paper or had it read to you and that you are willing to be in this study. If you don't want to be in this study, don't sign.

Name of student _____

Signature _____

Date _____

Appendix C

Instructions given at the start of the activity

Good morning

You will work in groups of on this activity. The groups are as follows (Names, as assisted by classroom teacher, are read off, groups assigned and positioned)

You have, at your table, some equipment (stopwatch, strings of various length, various masses, meter stick, ringstand, clamp, protractor)

You know that a pendulum is a device that swings back and forth like this (demonstrate a pendulum swinging)

Your job is to look at the equipment, think of questions, design something you will do, do that activity, record information, and see what you can learn.

I am interested in the questions you ask at the start and along the way. You have a large sheet of paper and a blue pen. When we start, you will use your blue pen to write down questions on the sheet that you have about pendulum motion and what you might do for an experiment. You will have a minute to write these questions – then you will talk with your group and decide what experiment you want to do. Every 8 minutes, I will give you a new pen that is a different color and you will use this. Also, every 8 minutes, you will have the chance to write down your questions. You will do all of your work on this large sheet.

I encourage you to cooperate as much as possible but only within your groups, not with other groups.

Wear goggles. Be careful not to swing the pendulum wildly. Be careful not to drop the mass on your foot. What other ideas do you have about safety (solicit input from students)

You will work with minimal assistance from me or your teacher. You should focus your questions and comments within your group. Before we begin, does anyone have a question about what you are asked to do? (not a question about pendulums)

Before we begin, you will speak into the tape recorder. You have been assigned a number – please take the recorder, say your number into it, and hand the recorder to the next person.

We will start by having you write your questions down for one minute on the green sheet of paper. Please work quietly and write your ideas down on the paper.

Begin – after one minute – say “You can start talking and working on this activity”

After 8 minutes – say – “here is a green pen” take a minute to write down the questions you have about your experiment on pendulum motion – you can write about any part of your experiment. You can also write down other questions about pendulums.

Every 8 minutes up to about 50 minutes, students will be given a new color pen and asked to write their questions down

My reference

Start -Blue

8 Green

16 – purple

24 red

32 orange

40 black

48 (if time) yellow

At the end

Please take a minute to write down any remaining questions. Also please write down what you learned about pendulum motion today.

Thank you

Appendix D
Interview Protocol

R: “Our main job here is to double check your written responses for clarity – let’s go through your questions and confirm that I am reading them correctly

Example : R: I see that at the 12 minute mark you asked “Is $P = len$? Would you like to clarify that a bit more for me?

(record clarifying response)

R:”I see that at the 24 minute mark you asked “How do we measure time?”

Do you wish to clarify what time you were measuring?

Did you have equipment set up?

Or “What had you done up to this point?” (attempt to ascertain position with Lawson model)

Also “How did you come up with this question?” (searching for abductive reasoning)

Thank you

Is there anything else you would like to say about your questions?

Appendix E Type of Question versus Inquiry Phase (TQIP) form (ultimately not used)

Question Type (to the right) Element of Lawson's model (Below)	Existence/ Affirmation	Essence/ Definition	Attribute/ Description	Cause/ Explanation	Difficult to classify type of question
Pre- Inquiry		What does period mean?			
1. Making an initial puzzling observation.	(is it the case that)Sometimes the period is the same and sometimes it is different?		(Is it the case that) mass does not affect the period?		
2. Raising a causal question.				Does length affect the period?	
3. Using analogical reasoning to generate one or more probable hypotheses.					
4. Supposing for the sake of argument and test, that the hypothesis under consideration is correct.					
5. Carrying out the imagined test.					
6. Comparing predicted and observed results					
7. Recycling the procedure					
8. Difficult to categorize according to Lawson's Model					

Appendix F Group Experience Accounts

The Experience of Group 1

Group 1 consisted of four female fifth grade students. For three of the four students, initial questions were about the general nature of pendulum motion. Student 1 asked six questions, one of which was “What is a pendulum used for?” student 2 asked three questions, one of which was “What can a pendulum do?”, and student four asked “How does a pendulum work?” among her five initial questions. In contrast, student 3 posed but one question “Can pendulum motion involve the earth’s movement if you make it big enough?” Students 1,2, and 4 also had questions about the string, paper clips, etc.

Observation Part 1

After students completed the minute of question writing, they began to investigate their materials. A student asked “Should we write down the materials?” and they then proceeded, after general assenting comments to each prepare a list that included 5 washers, ruler, stop watch, string, etc. This familiarization process with the materials appeared to give rise to questions as they discussed what the items were for. A student asked “Are we supposed to swing it back and forth?”, they attached a washer to the clip, swung it, and timed it, without really having a question. Noting then, that the pendulum bob reduced its amplitude, they began seeing what happened as they added washers.

Perception Part 1

The process of determining what question to address was mainly imbedded in the process of working with the materials. There was a “general movement” in the direction

of adding washers and recording the amount of time that the pendulum took to stop without a formal written or clearly spoken question such as “I wonder what the relationship between the number of washers added and the time it takes for the pendulum to come to a complete stop?” A review of the data they collected, as well as more specific responses to direct questions asked later by the researcher during the interview revealed that this was the relationship they were investigating. But at the time, there was more of a shared, implicit, fuzzy approach to the action of adding washers and finding the time to stop.

Observation Part 2

During the process of collecting data, there was a great deal of relatively polite “arguing” about what constituted the pendulum coming to rest after swinging – “Has it stopped?” – “Should we stop the watch?” were asked on more than one occasion. All four students recorded their data as follows

- 1 washer – 48 seconds to stop
- 2 washers – 2 minutes 13 seconds
- 3 washers – 2 minutes 47 seconds
- 4 washers – 1 minute 21 seconds
- 5 washers – 2 minutes 54 seconds

Note the trend of increasing time to stop with the number of washers added, with the glaring exception of 4 washers. Students did not register surprise at this anomaly.

As indicated in the description of the method of the study, students periodically wrote down questions. Students, 1, 2, and 4 continued to write down questions such as “How did it get its name?” etc. throughout the lab. In other words, these types of questions were written down even though the lab activity they chose to do was not at all about these questions.

Importantly, at about the 15-minute mark, student 3 wrote “there is something wrong with this experiment, the hypothesis would be wrong if we didn’t do this – we need to swing at the same beginning.”

Perception Part 2

Student 3 is writing about control of variables. Although it is difficult to be certain, it does not seem like this point got across to the group during the investigation. There was no detectable mention of this, and their actions do not reflect an attention to control of variables. Also note that student 3’s initial, more scientifically investigable question about pendulum’s showing earth movement was not addressed or heard by the rest of the group.

Observation Part 3

During the investigation, there was significant discussion, and oral questions within the group, about who should do the timing, who should start and stop the stopwatch, etc. There were frequent comments and questions within this realm that reflected a sense of norming and fairness, everybody should get an equal opportunity, with the occasional “I should get to do this” assertion. In relation to the key questions in the study though, it should be pointed out that a large portion of the questions were about fairness. “Can I do it?” and “you haven’t done this yet” were oft heard comments.

There were also questions, comments, and implicit questions about rounding data. The norming process was, for instance, that even though the stopwatch measured to 100ths of a second, they should round to the nearest second. “They aren’t exact answers.”

Perception Part 3

There was significant amount of questioning and discussion about fairness, sharing, and other social items. Also, “what’s appropriate?” was addressed with the rounding questions.

Observation Part 4

Student 4 did write, midway through the experience “The washer is very interesting because when it gets more it swings longer”. This is the most direct relationship that was mentioned during the study. At the end, when students were asked to jot down what they had learned, student 2 said “I learned that the more weight on the string, the longer it will swing.” However, during the follow up interview, when I asked about what they learned, there was concurrence that with more washers the pendulum would tend to take more time to stop.

Perception Part 4

There was some awareness and direct stating on the students’ part that more weight led to a greater time to stop. There was little concern for the anomalous data. However, it is possible that student 3’s concern about starting things from the same place stemmed from this anomaly. There was little discussion on the students’ part about why this might be the case.

Observation Part 5

After about 30 minutes of investigating, with about 10 minutes remaining, the question “Can we do another experiment for fun?” was posed along with the comment “We should try different things.” They then chose to use the protractor – not to measure

angles but to attach it and see how long it would take to stop. They also measured the time to stop with no washer at all.

At this point, the fact that a pendulum does not always oscillate in a single plane was discussed. “How many angles does a pendulum have?” was posed. “Angle” referred to plane of oscillation. The group noted that the pendulum could go in a circle and then ultimately go back to going in one plane.

Although length was measured, it was done so in a descriptive manner, and length does not appear to be a variable the students considered.

Perception Part 5

Students were more interested in moving on to new interesting questions than in confirming the relationship between their question and their data in a precise, controlled manner.

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson’s model of scientific method, the following comments can be made.

1. At the very start, when students were asked to pose questions, only one question was really testable. The others were of a general nature, just getting to know what the pendulum was and what it was used for. It should be noted that at this point, the students did not have much direct experience with the pendulum materials. The testable question (related to Foucault pendulum concepts) was not investigated initially by the group.

2. There was an implicit shared question at about the two-minute stage of inquiry that went something like this – “What will happen to the amount of time needed for the pendulum to come to rest if we add more washers?” This question was not directly stated, nor was a specific prediction (e.g. it will take more time to stop if more washers are added). Often, according to Lawson, a question can arise from a puzzling observation. It is not clear if the possible stopping of the pendulum was a puzzle, or if it was just assumed and considered something that could be investigated. The group just kind of fell into doing this. If there was an impetus for the question of investigation, it could have been that a stopwatch was provided. One of the students asked “Are we supposed to just swing the pendulum?” This is a question about what is it that the authority intends for us to do. However, the person who asked this question started swinging the pendulum with one washer, and another started timing it just to use the watch. They noticed that the pendulum was stopping – this observation, though not unexpected or puzzling, may have served as their impetus for further study.
3. Much was done in an implicit, informal way without forming a direct hypothesis. But there was a shared understanding that perhaps changing the weight would change the time to stop.
4. Without naming the phenomenon, students were asking questions about damping. This relates to friction and air resistance. None of these terms were used. It is not clear, from the interview or in – class comments, whether the students attributed

the stopping to friction and drag or whether they just felt like gravity pulls down so the pendulum should stop.

5. Not really fitting directly into Lawson's model of doing science, or Dillon's distillation of Aristotle's method of categorizing questions, there were many questions that related to the fairness and opportunity issues of who should measure, pull back the pendulum bob, time, etc. These social questions accounted for almost 25% of all questions posed.
6. There were questions, during the midpoint of the investigation, about how to measure. This fits within Lawson's model at this stage. There were many questions such as "When has it really come to a stop?" "What will we use this thing (protractor) for?" "How many washers are there?" "Are you ready to start timing?" (ready?) "Should we round off and to what extent?" (There was general agreement that this was not totally exact so they should round off).
7. When the students were at a point where they had collected data to the extent that they could compare it to their implicit prediction or to see what the data said, they quickly and glibly said the more washers the more time, and then started talking about what else would be interesting to investigate. So, instead of refining their research technique to get better data in light of controlling variables, they posed questions about what they could do next.
8. There were some comments, related to implicit questions, about why it stopped. Someone said that it stopped quicker because it was lighter. This in turn led to the prediction that an individual paper clip would stop very soon. They tested this

– it did stop soon. There was little jubilation or confirmation about this result – they just moved on to the next interesting thing of swing a protractor to see if this would match the prediction that one protractor was worth one washer. So, in a microscopic, rough and ready way, they formulated a test (Lawson’s model) that would confirm their unstated but roughly shared hypothesis, did the test, and compared the result to prediction – in a somewhat vague way that seemed to satisfy their curiosity nonetheless.

9. Finally, there were many “now that we are done’ let’s try something else” questions centered around the processing (how many angles?) of the plane of pendulum oscillation. This was something that they had noticed during their main study, and this puzzled them. They did preliminary inquiries in this area as time for the class elapsed.
10. In relation to the follow up interview question about where they got their ideas from, student 3 mentioned that she had been to a museum and had seen a (Foucault) pendulum and she wanted to know more about this. It is not clear where students may have borrowed ideas (abductive reasoning) to get their main question for investigation. There was perhaps an intuitive feel from past experience that things just stop because of gravity.

There was significant consistency in what was written down. All four students had the same values for data.

It could be argued that the “most scientific” question” was neither discussed nor tested. This was the question about inferring earth movement from the change of plane of oscillation of the pendulum.

The Experience of Group 2

Observation 1

Group 2 consisted of 3 girls and 1 boy. The boy sat next to the pendulum stand, operated the pendulum on a number of occasions, and used the timer on a number of occasions.

One of the girls recorded detailed data. At the start, the boy released the pendulum, and the group started counting the number of swings without timing the swings. The boy made a number of declarative statements, of the type “If you have 2 washers it will go quicker than if you have 1 washer.” Students read some of their initial questions to each other. While the pendulum was swinging, a girl asked “Are we supposed to do this?”

Perception 1

The boy’s actions strongly influenced the direction the group took. The students were not originally aware of the stopwatch or its use. The process of counting the number of times to go back and forth was not directed so much to answer a question, it was a sort of cognitive warmup or familiarization process. The “declarative statements”, though stated with confidence, could be viewed as questions by placing the phrase “is it the case that” in front of these statements. There was no data to support the statements when they were made. The students were proceeding along a pathway of data collection without a real shared or implicit question to be investigated. When one student asked “Are we supposed to do this?” the group reflected for a second but carried on with its work without adjusting.

Observation 2

Students did not vary the length of the string. About eight minutes into the experiment, the boy noticed the stopwatch on the table. In noticing this, he posed a question “not

fully audible” about the relationship between the number of washers and the time per swing. He then released the pendulum from an angle of about 20 degrees and timed the swing with a stopwatch. He announced to the other 3 members of the group that the time was “1 minute 25 – no 1 second 25 milliseconds” . Other students recorded this data. Student 3 wrote “Hypothesis – it will get faster if you get a washer”. Student 2 wrote “Does it swing more when more washers are added?” Student 4 wrote “How many seconds will it take two washers to go back and forth?”

Perception 2

The boy continued to do much of the activity. The question “What is the effect of adding washers to the time for a “lap”?” was now shared by the group but in an unclear way with different takes on this as shown by the different forms of written questions at this point. One student was doing most of the physical activity – all students were writing information in a clear manner. Students went quickly to the assumptions they had about what they were investigating without taking a minute to confirm a common direction. Student 4 was seeking a more direct, informational result, and the other students were looking for a more functional relationship in the data.

Observation 3

The sheets for all 4 students clearly displayed the following data

1 washer 1.25 seconds
2 washers 1.31 seconds
3 washers 1.34 students
4 washers 1.53 seconds
5 washers 1.62 seconds

This data was collected in the following manner – student 2 held the pendulum, released while “simultaneously” starting the stopwatch, waited and caught the pendulum at the “end” of one full back and forth motion of the pendulum, and stopped the watch “at the instant” he caught the pendulum. He announced the time to the other students in the group. For the most part, the other students did not see the watch, but on one occasion another student looked at it. It appeared that the paper clip was lengthened by a few millimeters each time a washer was added.

Post observation follow up investigation

This researcher reviewed the video recording of the students. Using the frame by frame advance feature of the video, the times for each swing were measured.

1 washer (deemed not valid – i.e, a complete back and forth swing did not take place)

2 washers 1.70 seconds

3 washers 1.77 seconds

4 washers 1.70 seconds

5 washers 1.70 seconds

(3 significant figures are used to match that number used by the students – one could argue from the students’ data collection method that two s.f. are more appropriate. In the case of the investigator, there were 30 frames per second, so each frame was the equivalent of 0.033 seconds – it is unlikely that this investigator erred by more the one frame, or 0.033 seconds, in the follow up measurements)

Perception 3

The data, as recorded, answers the question – more washers lead to more time per swing.

This contradicted the original declaration by student 2 “more washers makes it go faster”

– but this contradiction was not noted or stated by the students. The slight lengthening of

the clip does not account for the large difference in time per swing. (Note that this result

is not consistent with physics theory about pendulum motion-even if one accounts for

slight increases in length or change in amplitude. It could be the case that with each

additional trial, student 2 started his watch more quickly in anticipation of the release of

the pendulum, but this is not conclusive. The group adopted the norm of carefully recording the data. Note that this researcher's data does not show the trend described by the students; a more constant period, as measured directly from the video was obtained. Reasons for the students obtaining this trend include better anticipation of the start of the swing, leading to a longer time of swing, allowing the prediction to influence the start or stop time of the watch, or other factors. It does not seem likely that the student who announced the times said a number that was different than what was on the watch.

The possibility of air drag should not be ignored. However, for one swing, this friction would not produce the trend in the data that was obtained. More washers does indeed decrease the drag to force ratio due to a lower ratio of surface area to mass for more washers as their flat sides were adjacent. However, this difference could, by theory, lead to a slightly increased period for the pendulum with the least number of washers. Overall, it is reasonable to say that the effect due to friction would be less than that obtained by the students. Note that, even in the case of the investigator doing the timing right of the video, there was very little change in period compared to what the students said they got.

Observation 4

After this initial data collection activity, student 2 said – “Let's do another experiment”. The group proceeded to collect data on the number of washers added and the number of laps the pendulum completed in one minute.

Perception 4

The students were doing a more detailed experiment to check or confirm the results of their original experiment.

Observation 5

Students proceeded to collect data. Student 2 released the pendulum. Student 4 did the timing. All four students counted the pendulum swings out loud in unison. During the collection of data, students audibly noted (even after the second trial) the trend in the data.

The following data was obtained

- 1 washer – 37 laps in a minute
- 2 washers – 36 laps in a minute
- 3 washers – 35 laps in a minute
- 4 washers – 35 laps in a minute
- 5 washers – 34 laps in a minute

Post observation investigator activity

This researcher, after noting the student data for this activity, did the same experiment on his own the next day, with the same equipment and the pendulum at a similar length.

The data was as follows

- 1 washer – 36.5 laps in a minute
- 2 washers – 36.5 laps in a minute
- 3 washers – 36.5 laps in a minute
- 4 washers – 36.5 laps in a minute
- 5 washers – 36 laps in a minute

This researcher also reviewed the video of the students in action and obtained the following results

- 1 washer – 37 laps in a minute
- 2 washers – 37 laps in a minute
- 3 washers – 37 laps per minute
- 4 washers – 36 laps per minute (larger amplitude noted)
- 5 washers – 35.5 laps per minute (even larger amplitude noted)

Perception 5

Again, students obtained data not consistent with accepted theory. It is possible that with their pendulum, there was more friction at the pivot when more weight was added – or there could have been a slight lengthening of the string when masses were added. The students proceeded with their data collection and recording in a relatively orderly

manner. Their actions and writings indicate a beginning development of the idea of the period of a pendulum, or perhaps more directly, of the concept of pendulum frequency, i.e., 37 laps per minute.

Observation 6

At the end of the activity, students wrote down what they had learned.

Student 1 “ It takes 1.25 seconds for the pendulum to swing back and forth with one washer” , “Adding a washer makes the pendulum swing slower”, “the pendulum can swing 37 laps in one minute with one washer”, “the number of laps goes down almost every time we add a washer”.

Student 2 “When you add a washer to the penquillen it pretty much takes one lap.”

Student 3 “Wobblier each one added”, “goes down by one lap each time”, “I was right as usual”, Pendulums swing back and forth”

Student 4 “In experiment 1, adding a washer makes it go slower”. In experiment 2, every washer you add it goes one less lap in a minute most of the time!”

Follow up calculations by the researcher

# of washers	Time recorded by student for one swing	Number of laps recorded by students for one minute	Period from one minute trials	Comments
1	1.25	37	1.62	
2	1.31	36	1.67	
3	1.34	35	1.71	
4	1.53	35	1.71	Researcher noted amplitude increase
5	1.62	34	1.76	Researcher noted amplitude increase

Perception 6

The data does support the comments made by the students about what they learned. Some students found it important to write down specific about one measurement as what they learned. There are a variety of interpretations of the data. Although student 1 did not participate actively in the physical process of data acquisition, she wrote down meaningful, direct statements about what the data said.

The data obtained by the students for their two experiments is internally consistent. An increase in period with washer increase, as noted in experiment 1 by the students, is

consistent with a decrease in frequency with washer increase as noted in experiment 2.

The effect is greater in experiment 1 (perhaps due to collecting data for just one swing) than in experiment 2 (data for one full minute). The students may have found these data to be consistent on an intuitive basis, but they did not perform or mention calculations that would show this consistency.

The effect of friction on the period of a pendulum over time is difficult to ascertain.

However, it should be noted that that, say, 10th swing of a pendulum with less friction would be greater in amplitude than the 10th swing of a pendulum with more friction. This factor, by itself, is in the direction of increasing the period (decreasing the number of swings in one minute). However, the factor of friction itself and its impact on period is difficult to ascertain

Observation and Perception 7

At the very end, it occurred to student 2 that it might be a good idea to move the lab equipment in front of another student so that she could record data. This took place but time in the instructional period ran out before the group could do a third experiment.

Some learning about sharing belatedly took place.

Observation 8

During the interview, the investigator drew the students' attention to the fact that the length of the pendulum could be changed. Data was collected that showed that the number of laps for 60 seconds depended on the length. Students were then asked to carry on a further investigation. The students chose to investigate damping; they measured the time for the pendulum to stop.

Perception 8

The students were reluctant to investigate the relationship between length and period, despite learning about this potential relationship from the investigator during the interview. During the interview, given some time to work on their own, new investigation, the students chose to investigate damping. It is possible that there is some cognitive need to gain an understanding of the pendulum stopping versus the ideal of continuous motion.

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson's model of scientific method, the following comments can be made.

1. One student made declarative statements that were more predictive in nature. The statements could have been turned into questions by inserting "is it the case that" in front of the statement. The declarations that were made were not on the basis of data collected but were preliminary statements that may give evidence of borrowing ideas from past experience. However, further questioning did not reveal the source of these ideas.
2. There were a number of "pre - inquiry" questions such as "What is it?" "What can it do?" "How does it work?". These questions were addressed in preliminary fashion as students (particularly on student) spent the first 8-10 minutes making measurements without a question, seeing how the pendulum swung, etc. Student 3 asked "What can it do?" and the first time she used the pendulum, she positioned the bob 30 degrees from the vertical opposite from her - she released it and was

surprised to see that it passed vertical and struck her (slowly) on the hand. She moved out of the way during subsequent trials. But this initial action gave her necessary information about pendulum motion that was needed before further questions would take place.

3. The questions at the “hypothesis” stage were at first nonexistent. There was a vague, shared understanding that it would be good to see how long the pendulum took to swing with different numbers of washers. As the data collection progressed, student 3 hypothesized “ It will get faster if you add a washer” She then later said “conclusion – it actually goes slower”. This student was realistic about how the data compared to her hypothesis.
4. Lawson’s “recycle the procedure in light of data in relation to hypothesis” step was evidenced in a beginning form. It took the shape of a shared implicit approach that consisted of the vaguely stated question “If we collect more data, with more time per trial, will we get results similar to our first experiment?”
5. On one occasion, student 3 asked “should we add this plastic thing (protractor) to the string and see what happens?” Student 2 said “it is weightless” and this was not investigated. For this group, on occasion, student 2 offered an “authoritative” voice that served as an answer that was not confirmed by data.
6. Early on, there were some basic, informational questions, such as “How many seconds will it take 5 back and forth? Just a bit later, there were more relational questions such as “Does it swing more when more washers are added?” This said, it should be noted that the students proceeded with their data collection in

the absence of a clear, precise question; yet their actions were purposeful and directed towards the goal of seeing the effect of the number of washers on the number of laps per minute.

7. The following progression of questions and comments took place through this activity

Ca. 1-2 minute mark – How long does it take? (how long does it take the pendulum to do one full swing)

Ca. 4 minute mark – Will 2 go quicker than 1? (will the pendulum swing more quickly with 2 washers on the clip than with one washer on the clip)

Ca. 8 minute mark – Does it swing more when more washers are added?

(“translation” not completely unambiguous)

Ca. 15 minute mark – What we figured out was that adding a washer makes it go slower

Ca. 15.5 minute mark – Ok – so that was experiment 1?

Ca. 16 minute mark – How many times will it swing in one minute?

(followed by collection of data for one minute each for 1,2,3,4,5

Ultimately – students were interested in “period” as a function of # of washers added

Ca – 30 minute mark – What is our next experiment?

Ca 32 minutes – new idea – how far does the washer go?

The Experience of Group 3

Observation 1

Group 3 consisted of 3 boys. The original written questions of student 1 were “What does a pendulum do?” , “What are we gonna do?”, and “Are we going to use other things?” Student 2 asked “What are we going to do?” and this is essentially the only question he wrote down over the 45 minute activity. Student 3 wrote “How long is the stamina?” Again, this was the only written question posed by student 3 during the activity.

Perception 1

The students were not apt to write their questions down. The question “How long is the stamina?”, though anthropomorphic in nature, revealed some insights into the concepts of friction and energy in relation to the time needed for the pendulum to stop.

Observation 2

After starting the physical portion of the activity, the students orally posed questions and made statements at the outset such as “What are we going to do?” “We have to measure....” “What do you mean by measure?” “You’re not supposed to use your watch.” “use the stopwatch.”

The students began swinging the pendulum and measuring the time needed for it to stop. Discussion took place about “What to do”. Specific “commands” were uttered such as “Just let it go.” Don’t stop it.”

Perception 2

The students were gaining practical familiarity with the pendulum materials, measuring devices, what a pendulum does, how it swings, and how to measure. They were proceeding roughly along a direction of “How long will it take it to stop?” without specifically stating this measurement question. However it was a vaguely shared question by the group of 3.

Observation 3

Student 1 made the statement “My hypothesis is 3 minutes 30 seconds. Other students made similar statements. As the activity progressed, the students began to write down each student’s prediction as to how much time it would take the pendulum to stop. They made “careful” measurements as to how long it would take the pendulum to stop.

Perception 3

The students began competing with each other, in a relatively organized way, as to who was the best at predicting how much time it would take the pendulum to stop. This provided a focus to their activity.

Observation 4

Data was collected for different amounts of washers and the time taken to stop. Comments such as “It’s still going!” “None of the hypotheses was right.” “I was closest.” “That thing would have gone on for an hour”

Perception 4

Questions about the fairness of when to say the pendulum had stopped took on added importance in light of the competitive atmosphere. The understanding of when a pendulum would stop was interwoven with the competitive nature of their approach. The

students wanted to make correct predictions as to when the pendulum would stop and they looked for and assumed patterns in the number of washers versus the time to swing. The “that would have gone on for an hour” is again a comment about friction and energy without naming these concepts.

Observation 5

Student (1): How long will this (set of) washers go?

Student (2): I’d like to find out why this goes so long! (Point of emphasis in student’s voice)

Student (3): I know why it’s going slow – you put so much weight on it

2 minutes later

Student (1) – to student 2 or 3 – “So why did you guess 3 minutes?”

Student (2 or 3) Because if you add more weight...

Student (2 or 3) Why does it go so long?”

Other comments – “(S3) is gonna win”. And “I’m gonna win no matter what” and “guys what’s your hypothesis for this one gonna be?”

Perception 5

Although students had not reached a formal conclusion as to their data or what it meant, they were employing tacit views on the patterns in making the prediction. The competitive nature of the activity continued in a relatively good natured way. Students began asking each other about why they were making certain predictions, and fragments

of reasoning behind the predictions were produced. The words “prediction” and “hypothesis” were used almost interchangeably.

Students were beginning to show interest in the mechanism(s) behind what was happening. They were starting to ask “why” questions without formulating a test that would get at what the mechanism was. Dialog approximating beginning “science talk” was interwoven with discussions about competition.

Observation 6

Students placed a protractor at the top of the pendulum and began making angle measurements. Comments like “It’s still going from 80 to 80 (degrees)” were made.

Perception 6

The students began to vaguely realize that amplitude could be a variable, but they never formally stated this, controlled it, or varied it. They did not apply control of variables to their investigation.

Observation 7

At the very end of the activity, the following fragments of discussion were recorded

S(1) – description of the idea that more washers leads to more time

S(2) – You didn’t come up with it – someone else knew this a long time ago

S(3) – We should explain why we guessed that number

Perception 7

Students were grappling with personal ownership of ideas within the context of existing knowledge and authority

General perception

This group of students wrote very little down and made many comments to each other, as well as questions, about the activity. Students chose damping as their area of interest.

Observation 8

During the interview, students were asked about the competition by the researcher.

R: Were you guys trying to see who was the best predictor?

S: That was a fun kind of thing as we tried to learn about the time

S: We put more on as we go... (meaning – more weights on the pendulum each trial)

S: Less decreases it (the time to stop)

R: What did you learn?

S: More weights, the slower it goes

Perception 8

The students used the competition to carry along the investigation. They learned that more weights on the pendulum meant more time to stop.

Observation 9

During the interview, students were asked by the researcher about the source of their questions.

Comments in response were varied and of the form “It has to stop, otherwise it would defy physics and gravity.” Continued comments were made about energy, continued motion. S2 asked “Is there a way to make it so that it wouldn’t stop?” “What is that way?” and another student continued the discussion with comments about using the

battery to run it but then the battery would run out. Or if you had it plugged in, you “would have to pay your energy bill and if you stopped paying it would ultimately stop?”

Perception 9

The students were engaged in ideas about friction, energy, and perpetual motion. They formulated questions and stated assumptions without devising tests to check these statements. The level of engagement was more fully evidenced by the competitive nature of their actions and dialog than by the written comments they made.

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson’s model of scientific method, the following comments can be made.

1. The students wrote down very few questions.
2. At the start, there were some written and oral statements and comments that were ‘pre-inquiry’ in nature.
3. The question “Who is best at predicting?”, a social question, was the most prevalent throughout the activity. It was a key driver in the students’ investigation.
4. Carried along by the competition was an unstated, or partially stated question about what would happen for the time to stop of the pendulum as a function of the number of washers added.
5. Students asked each other about why they thought what they thought and why they made specific predictions..

6. Towards the middle /end of the activity, even though the hypothesis “more weights means more time to stop” was only partially and inconclusively supported, students began asking why this was the case.
7. The measurement question “What constitutes stopping?” surfaced more than once
8. General questions about what would be needed to keep the pendulum going took place.

Although there were a small number of written questions, there were pre-inquiry basic questions such as how to measure, what to do, and what to use.

There was a shared and vaguely held hypothesis along with a loosely formulated approach to testing the hypothesis. Data collection took place without a formalized “ok we will do this to test this”.

There were questions about how to measure and what to measure

There were questions, vaguely formed, about how the data supported the hypothesis, intertwined with competitive comments.

There were questions about why it is the physical case that the conclusion was valid- why is it that more weights means more time to stop.

Final note about group 3 – near the end of the activity, when students were determining the winner, one of the students said “no one cares – we just want to learn what is happening”

The Experience of Group 4

Observation 1

Group 4 consisted of 4 boys. Original questions were, for instance “What does a pendulum do?” (2 students). “What is a pendulum made for?” (3 students with questions very similar in content) and “Why do we need goggles?” (3 students) . Student 4 did pose the question “How do you make it go faster?” The students in the group began their activity by making social comments and making playful noises. The comment that originated action was “You don’t know how this works!” (point of emphasis) In response a second student said “Yes I do!” and follow up comments included “Well you have a watch and....(other equipment)” . The students began swinging the pendulum with one washer on it and began doing preliminary unspecified timings of various pendulum actions.

Perception 1

The students’ introductory questions were of an essence “What is it?” nature. They were interested in what a pendulum was and how it worked. Student 4’s question “what makes it go faster?” was not directly absorbed or heard by the group, even though it could have been crafted into a testable question. However, the group proceeded roughly along the lines of this in a vague, shared understanding manner. The styles of communication were such that challenges and responses, as opposed to questions, were the basis for action.

Observation 2

The students began checking to see how long it took for the pendulum to take 5 swings with different numbers of washers. The amplitude was not measured. After some of

these preliminary measurements were made, the following questions were written at the 8 minute writing interval;

Student 2 – “How long does it take to go 5 times?”

Student 3 “Does it go faster when it has more weight?”

Student 4 “How long does it take to go 5 times?” and Does it go faster when it has more weight?

Perception 2

The students were transitioning from basic knowledge and measurement questions to questions involving relationships between variables. The variables were not carefully defined. They gained practice with measurement and as this became relatively automated, they sought relationships in the variables. The action of timing 5 swings relates to “period” but the questions included terms like “faster”. They did not yet have a shared understanding of exactly what they were investigating.

Observation 3

The students began collecting data. This was written down in various locations on their sheets – but not in tabular form.

Student 3 wrote, over a 20 minute span of time,

The pengulum takes 9 second swing 5 times with 2 weights
 The pengulum takes 8 seconds swings 5 time without weights
 “ “ 8 seconds swings 5 times with 4 wiegts
 The pendulum takes 8 seconds swings 5 times with 3 weights
 The pendulum takes 8 second swings 5 time with 3 weights
 The pendulum takes 6 seconds swing 5 times with 3 weights

Other students wrote down other times, such as 8.88 seconds, 9.25 seconds, etc.

During this process, one student would say to the other “Let me do it” and the tasks would rotate.

Student 3 said “ I think I see a pattern”.

At various times, data would be collected – the result would be announced – followed by ‘no- that’s not right’ and another trial would be conducted.

Perception 3

The students all got opportunities to do the various tasks of timing, counting, etc.

Students wished to “see it for themselves” to accept the data. Students were beginning to see patterns in the data and would repeat trials on an ad hoc basis to get expected data.

Note that from a physics standpoint, there should essentially be no difference due to mass itself in the period measured. Opportunity to participate was shared equally due to equal assertion.

Observation 4

As data was collected, the following comments were made “How long was it?” and “These are called washers, right?” as well as “I don’t believe it – let’s try again”. “That sounds more like it” “Let me try it”

Perception 4

The students were checking and refining their measurements. They were “questioning each other” by having different people measure. There was a sort of understanding that fairness in who timed it was related to some degree of truth in the data. Students were reluctant to trust one data trial, especially if it did not fit an expected pattern, but there was no systematic collection or recording of data in a controlled manner.

Observation 5

The following statements were made over the time range 25-35 minutes in this 45 minute activity.

“I think it is slower with less weight”

“More weight going down – that affects it”

“I think it takes longer...”

“I think it takes more with more weights”

One student said in a fairly direct manner “ When you count – you have to go that way and back”

“It got quicker all the second times”

Student 4 wrote “ “with 4 it went slower than 5” “3 went slower than 5,4, and 1 weight”

“2 is slower than everything”

Perception 5

It is difficult to know at this point if the students were in agreement with each other about what they could conclude from their data. At this point, though, the students did have an explicit statement about how to measure the period of a pendulum. Note that this more precise definition was generated well into the data collection process. The lack of clear, shared understanding about what the data said could be related to the fact that the data did not fall into any particular pattern (as a physicist would expect- the differences were mainly due to differences in measuring, reaction time, etc.). Student 4 was reluctant to generalize – he just made pragmatic comparisons without stating a pattern.

Observation 6, Perception 6

During the interview, students were guided by researcher questions in the direction of how the length affected the period. The researcher had the students collect data for three different pendulum lengths – the time to take 5 swings at each length was recorded. The researcher then asked the students to ask some of their own questions. In other words, a more focused “mini-version” of the previous day’s activity took place. After being exposed to the length/period data collection, the students wrote the following questions

Student 1 “ “if we put up the string really short and had all the weights on how long it would take or would it?”

Student 2 “ “Would the pendulum go faster or slower with the rope shortenend nd the weight less or not?”

Student 3 – “More weight more velocity?” “More down force if it has more weight?”

Student 4 “If you pull the string farther back would it go faster?”

The students were then asked by the interviewer, “bowling style not ping pong style” to read off their questions one by one, listen, and then select a question for study.

The students did this. They selected student 2’s question about length and mass. Note that instead of assuming mass had no effect, the observation of the effect of length led to forming a question and investigation about the combined effect of both length and mass.

During the interview, no evidence was obtained of the use of abductive reasoning in forming the questions.

General perception

This group of students was not fully engaged in this activity. However, they did reach some insights into what the period of a pendulum was. They were seeking a pattern in a

realm of pendulum motion where no pattern was to be found – this could have potentially led to the interesting and fruitful conclusion that the amount of mass on a pendulum bob does not affect the period of motion, but more careful controlled measuring was needed. The choice of “time for 5 swings” was a reasonably advanced view of measuring the period of a pendulum. It would have taken a fair amount of confidence and insight to reach a point where they could say “no difference”

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson’s model of scientific method, the following comments can be made.

1. The students began their process with some pre-inquiry “what is a pendulum and what does it do?” basic factual questions.
2. They proceeded to start their inquiry on the basis of “challenge” type comments that, though not questions, served as an impetus for action.
3. The collection of data proceeded in the absence of puzzling observations or specific questions. There were “basic measurement” questions at this stage, though, such as “How long does it take 5 times”
4. As the vehicle of data collection continued to travel through multiple trials, questions started forming. These were not necessarily related to puzzling observations, but rather, to perceived patterns.
5. The students did try to make sense of their data – but they did not have a shared question to compare to – so each student chose different types of comparisons to make

6. The conclusion “there is no significant difference” in the data would have taken more cognitive confidence than existed. This is a realistic comment about the difficulty of making such a claim.
7. As the experiment progressed, further refinements in measuring technique and definitions took place.
8. For these students, the entire 40 minutes could, to some extent, have been considered pre-inquiry – they were ultimately in a place to make an observation and ask a testable question in a clear manner.
9. To the students in this group, validity in data was related to direct personal experience in measuring the data one’s self – and there was a shared value that it was permissible to be assertive to forge the opportunity to collect the data for one’s self.

The Experience of Group 5

Observation 1

Group 5 consisted of 2 girls and 2 boys. Written questions posed at the outset included, per student

- 1- "Why a pendulum?"
- 2- "How far can a pengilum swing with one push?"
- 3- "Will the pengelum swing differently if we put weight on it?" and Will the pendulum swing faster with more weights on it?" and 3 other questions
- 4- "Where did the name pendulum come from?"

When the students began their activity, they posed further questions, such as "Why are we using a pendulum?" and "Isn't it used for hypnosis?". The comments "It's kinda like a swing." And "that could be like a bungee cord for rats" were also made.

Perception 1

The members of the group originally had questions that ranged from basic, factual needs for information about what a pendulum was to more relational, functional, testable questions.

Observation 2

The comment "Let's try 2" (washers) was made at about the 5 minute mark. Students began counting the number of swings that would take place with one washer. (To clarify, the comment "let's try 2" was not directly applied). Orally, the comment "about 150 swings with one washer" was made. Student 3 recorded "about 150 times to w/ washer until reaches metal thing." No other students recorded this information.

Perception 2

The students were investigating the number of swings for the pendulum to stop. They did not really have a shared functional question at this point, such as “what is the relationship between the number of washers and the number of swings to stop?”

Observation 3

Student 2 wrote the question “How long can it swing for?” at the 8 minute mark. At this time, student 4 wrote “How long can it keep going?” The students began collecting data with different numbers of washers. At about the ten minute mark, the use of the stopwatch was incorporated. At about the 14 minute mark, student 3 wrote “Done- 4 m and 28 ms – 2 washers”

Perception 3

The students were at different places in their thinking about the experiment. They did not have a shared understanding of exactly what they were investigating. But, they did transition, intuitively, from counting swings to measuring the time to stop. The students were progressing in the general direction of checking to see how the number of washers attached to the clip affected the amount of time to stop. Though not directly documented by questions or comments, they were working towards an agreement of what constituted “stopping”.

Observation 4

Student 3 filled her paper with questions and information. She had approximately 400 words on her page.

Student 4 wrote down 2 questions and wrote down roughly 40 words on his page.

Students 1’s data / question page was similar in appearance to that of student 4.

Student 2 had approximately 90 words on her page.

The concluding statements written at the end of the activity were as follows

Student 1 – It uses wait and force to rock back and forth. It does sertian things with sertian angles

Student 2 - I learned that a pendulum is an object that swings back and forth. I realized that different objects on it ment different swings and longer and faster swings.

Student 3 – A pendulum rocks back and forth. This pendulum has a green paper clip on the end. Some pendulums paper clips fell off. I used a ruler to measure a pendulum. I have learned that putting weights on the end of a pengulum makes the pendulum swing longer. Each swing is about 1 second each, 2 for round trip. Holding the end of a pendulum higher makes it go longer. Safety goggles are essential. (Diagrams also included)

Student 4 – The weight of the swinging object can effect the weight of the bigger object.
Perception 4

There was a significant difference in the amount written by the students.

The students wrote down significantly different concluding statements about what they learned. Student 3 wrote down a large amount of concluding statements. Some of these were basic in nature, but she did also say “putting weights on the end of a pengulum makes a pengulum swing longer.” She was the only student in the group to make this relational statement.

Observation 5

Various comments such as “The washers fell off” or “the weight is shifting” and “It’s like it’s a diagonal angle” and “it keeps hitting the table” were made

Perception 5

The students had difficulty obtaining data. They also had difficulty distinguishing between an experimental anomaly (diagonal angle) and ineffective experimental procedures.

Observation, Perception 6

There was a lot of social talk taking place by this group during the activity. Student 3 was the only student who was consistently engaged. The opportunity to write gave student 3 the opportunity to express her thoughts, questions, and ideas even though these were not always received or understood by the other members of the group.

Observation 7

During the interview, the researcher if there was more information they had obtained during the activity than what they had written down on their papers.

Student 3 responded “Well, I basically wrote down everything.” (Indeed, her page was full of information) She added “I thought it was interesting that it was too much weight for the string.”

Another student mentioned “Well, the pendulums swing differently if you put weight on it.”

Further prompts for more specific information by the researcher resulted in information about the amount of time it took to swing with 4 washers, etc. After further discussion, student 3 said “If you put weights on it, it will make the pendulum swing longer.” The

researcher asked for further clarification, and ultimately, S3 concurred that this meant a longer time before the pendulum stopped.

Perception 7

Although the students made comments after prompts about what they had learned, there were few direct comments about a relationship between one variable and another.

Student 3 did say that more weights led to a longer swing, but she was not originally clear about what “longer swing” referred to. The students in the group did not have a shared, unified sense of what they had investigated.

Observation 8

During the interview, the researcher asked the students where their questions came from.

S1 responded “What it looked like and the shape. What supplies we had.”

S2 mentioned “We were given the washers and I thought “ Hey, what if you put washers on this and see how far it goes?” Other students agreed in general with these comments.

Perception 8

The student questions arose less from apst experience and more from the direct, real time observation of the supplies in front of them.

Observation 9

During the interview, students were asked, in various ways, why they thought the pendulum would ultimately stop swinging. Answers from various students are as follows

S – “Because the force and weight would ...the weight would eventually weight down with force and it would stop moving so fast. It would make it heavier instead of light”

S3 “ But sometimes we actually had to force it to stop because it just kept going.”

S (It stops)...”cuz all things stop”

S “I think all things stop.”

All students in unison “All things stop.”

S “except numbers”

S “except in space”

The researcher then asked what would happen if this was done in outer space. Responses included

“It wouldn’t stop, it would keep going.”

“Yea, the gravity would”

“It might not swing, it might just like stay there.”

Perception 9

The students were grappling with fundamental questions about friction, gravity, and inertia without direct experience or formal theory. Their assumption that it would stop was based on a variety of “theories” about how the natural world worked.

Observation 10

During the interview, the researcher asked the students if they had posed any other questions. These included

S “how far can it swing with one push?”

When asked if they had answered this question , the response was “No”

Students were also asked if they agreed that more washers attached to the pendulum related to more time for the pendulum to stop. They agreed that this was the case. At this point, the researcher asked if this realization led to further questions. The answer

S “ I wonder how long it would take with more than five washers on it?”

Perception 10

Students were able to say, with significant prompting, that for their four washers, more washers meant more time to swing, but it was not clear to them what would happen if you added more washers. In other words, their generalization was not very specific or complete.

Observation 11

During the interview, the researcher, in a fairly direct manner, introduced the idea that length could be a variable and that one could measure the time to do 5 swings. In other words, students were led in the direction of the relationship between length and period. They were then asked if they had a question they would like to research. They were given a minute to write their question(s) down on the back side of their data/question sheets. The questions were as follows

S1 – “How long for 10 swings? Does the washers mess with the speed? Depends on angle?”

S2 – “ How fast can a pendulum swing within 5 swings?”

S3 - “Is five, if you count all of the 5 swings together, would the time for all of them be over fifteen minutes?”

S4 – If we used bigger washers, would it make the time for the 5 swings faster?”

Perception 11

Despite being led to the idea that length could affect period, the students asked questions about mass and period, and about other aspects of the swing of a pendulum. Students

were interested in initial questions about whether each swing of a pendulum at a given length would take the same amount of time as the next swing. They had not necessarily formed the idea that all swings at a given length would have roughly the same period. It is not completely clear whether or not they understood that 2 different swings at the same length and amplitude would have the same period.

Observation 12

Students proceed, during the interview, to do an investigation to see how the number of washers affected the period. They did different trials with different numbers of washers and recorded this data.

Perception 12

The students proceeded more purposefully during the interview than during the activity. Mass remained a variable of interest to the students.

Observation 13

During the interview, while students collected data, the following interaction took place

R “When you say one, what is one?”

S “One swing set.”

R “What is a swing?”

S “when it stops”

Further discussion between R and S helps to clarify for all students that by one swing one full back and forth motion of the pendulum is considered

As students continued their data trials, they began to write down their data.

The following was written on S2’s page

4:13 seconds for five swings with 3 washers

4:97 seconds for 5 swings with 2 washers

4:38 seconds with one washer

When this last piece of data was collected, the following interaction took place

S – “It was faster?”

S – “That’s a little slower”

R – So you seem ...like that number isn’t quite what you expected...Can you elaborate on that?”

S “I thought it would be ..it’s a faster time, it took less time than the last one

R “What number did you expect?”

-----further discussion--- then

S “ I thought it would be more?”

R “More or less than 4.97?”

S “I thought it would probably be more?”

R “ because of the trend?”

S “Yea”

After further trials, then..

S “It seems like it depends on the angle”

Further discussion

Then students agreed that they would vary the angle and collect further data

Perception 13

Students made a “puzzling observation” that the data did not follow the expected trend.

They then began considering the idea of amplitude as a possible explanation.

Observation 14

During the interview, students continued to proceed with their investigation, this time varying the amplitude. The following interaction took place after the students had some data (only two or three trials) that seemed to indicate that a lower amplitude meant a lower period.

S “ ok I know why – the lower it goes it doesn’t have as far to swing”

Other S “ Let’s try it at 30 degrees”

--- further interactions – the time of 3.87 seconds is obtained—

S ‘That was actually slower”

S “That was actually slower!”

S “So maybe you have to get it at just the right angle”

S “Because if you put it too low it would slow down”

S “If it’s too high it will be too long”

Perception 14

Students were anticipating trends in their data and noting interest when it did not follow the anticipated trend. They came up with the explanation of “optimum angle” to produce the smallest period

General Perceptions

The interview and resulting structure allowed the students to proceed in a more orderly, shared fashion and to investigate their ideas and record their data. Students began noting puzzling observations and formulating explanations for their observations, along with plans to investigate this. Their follow up investigations resulted in a general idea to control variables that was not executed in an organized manner

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson’s model of scientific method, the following comments can be made.

1. At the beginning, students posed basic, factual questions. One student, however, posed a relational question about weights and time to swing.
2. The students proceeded with activity without a shared understanding of the question they were investigating. Therefore, there were a variety of different questions at the beginning.

3. Damping, or the time for the pendulum to “stop”, was the topic area of investigation. As the experiment progressed, students worked towards a shared understanding of stopping.
4. The students did not ask sufficient questions of each other to clarify their procedures for collecting data.
5. The students did not record their data in an organized way. Nevertheless, they reached the general agreement that more washers related to more time to stop.
6. The student questions arose at first, not from a puzzling observation, but rather, from observing the materials to be used and the sense that varying these could form an investigation.
7. During the interview, the students followed a path more similar to that proposed by Lawson, but it must be acknowledged that they were guided by the researcher. Nevertheless, there were two occasions where puzzling observations during the collection of data led to questions and experimental procedures.
8. Students did not fully complete their test and analyze their data to see if their ideas were correct, even though they did not run out of time to do so. Rather, they proceeded without a clearly formed idea, formed a general idea from observation of data trends, then quickly accepted it without reflection or careful review

The Experience of Group 6

Observation 1

The 5 members of group 6 (4 female, 1 male) wrote down many introductory questions at the start. Student 1 wrote down 8 questions, such as “What is pengalin motion?” and “Does it have a job of making the environment?” Student 2 asked 5 questions, including “What does it do?”, “What happens when it starts moving?”, “What do the washers do?”, and “What does it do for earth?” All of the other three students had a mix of questions about the environment and questions about the basic nature of pendulum motion, including “What is it used for?”.

Perception 1

None of the questions set a practical direction for investigation, although a few questions were of a nature that they could ultimately lead thinking in the direction of research, such as “What are the washers for?” Students were interested in finding relevance of the pendulum to their lives and how it could help the environment. In other words, from the standpoint of motivation, big picture questions were of more importance to these students than investigable questions.

Observation 2

Approximately 16 minutes of experiment time elapsed before the group formulated a question to investigate. Students spent time reading their questions to each other, checking on the equipment, asking about what the stopwatch was for and how it worked, just doing a practice timing of some swings of the pendulum, and making observations like “When it gets heavier it starts going whacko” and “It only works from one angle.

There were preliminary attempts at attaching washers and making measurements of length and time. Comments such as “we should add a washer” were prevalent.

Perception 2

The students were going through the process of learning what pendulum motion was and becoming familiar and comfortable with it. They were also transitioning from a stage of being uncomfortable about asking questions that they could answer by experiment.

Students wanted to see what would happen in certain cases without risking a question.

Few questions were asked but questions were imbedded within procedural suggestions.

Observation 3

The comment “We’ll just add another washer to see if as it gets heavier it goes slower. A student said “”When it gets heavier it goes slower”. There was not a specific comment about what “slower” meant. Students also noted that adding washers “made the pendulum go more diagonal”. One student wrote down the question “Does weight have an effect on which direction it swings?”

Perception 3

Students were getting started on their investigation in an implicit, partially shared understanding manner. The question “How does the number of washers added to the paper clip affect the amount of time it takes for the pendulum to stop?” was being investigated despite the fact that they had not formally posed this question or defined “time to stop”. There was a vague shared meaning that “time to stop” was the same as “going slower or faster”.

Observation 4

Data and observations written down by the students include “as it gets heavier it doesn’t swing in a straight line and goes crazy” was supported by “with 3 washers it started then went diagonal” and “with 1 washer it goes in straight lines”.

Another student wrote “It was a minute and 6 seconds until it went a little slower”. This was the only numerical data on the students’ page. Other students had this same comment about the one time or no comment.

Students made the written comment “When it gets heavier it goes slower”

Perception 4

Students were willing to make a generalization without supporting it with written, numerical data. Their generalization was based on more informal observations, even though they did time the swings for the pendulum to stop. There was a lack of precise measuring of the data.

There were two different, and not necessarily competing, research questions being addressed. One was about how the addition of washers could possibly make the pendulum swing in different directions. Another was about the relationship between the number of washers and the time to stop. Students did not “need” written data to reach their conclusions

Observation 5

Near the end, a student said “This is really cool – when I spin it it starts to go around and go in different kinds of circles”

Perception 5

Finally, near the end of the activity, this group made a “puzzling observation”.

Observation 6

During the interview, students were asked about their experience. After some discussion, it became evident that one of the questions the students were investigating was similar to “How does the number of washers affect the time to stop?” Students were asked if they had data to answer this question – comments in return by the students were not specific. One student said “if you put a brick on it, it would go super slow”. As the discussion continued, one of the students asked “Why do we have rulers?” this in turn led to “Does length make a difference?” Finally, during the interview, students were asked where the questions came from. Student answers were varied, but one of the responses was “By looking at it.”

Perception 6

Students in group 6 had difficulty formulating a testable question, writing down data that would answer the question they had, controlling variables, and using their data to answer the question. Nevertheless, students did reach the conclusion that more washers would relate to the pendulum taking more time to stop. The equipment itself, including the measuring equipment, served as a stimulus for student questions. The observation of the ruler led to “how can we use this?” and “Does length make a difference?” Note that the question poser did not specify the output variable in the last question. In scanning for abductive reasoning, little specific evidence was found, although there were some comments by students to suggest that past experience with methods of measurement (e.g. measuring length or time) gave them ideas about what they could measure. In fact, the awareness of what could be measured appeared to be linked to what could be

investigated. More general arguments were used than reliance upon specific data to reach conclusions.

Categorization of the Questions

In tracking the flow of questions posed as a function of time or as a function of Lawson's model of scientific method, the following comments can be made.

1. There were a large number of "pre-inquiry" questions posed by the members of group 6. Questions of relevance and environmental impact / positive effect were raised at the beginning, as well as questions about the stopwatch, meter stick, etc.
2. The pathway towards investigative action did not include a clearly stated question – students began researching the effect of number of washers added to the time it would take the pendulum to stop. The variables were not identified.
3. The existence and observation of the stopwatch was the closest correlate to Lawson's "puzzling observing". "How do you use this stopwatch?" led to practice with timing which in turn led to an approach to gaining information about pendulum motion.
4. Students in group 6 did not really evaluate their results against their question. Rather, as the "experiment" progressed, a second puzzling observation was made about the different planes of oscillation of the pendulum (the students called these "angles"). One student wrote down that the addition of more washers caused more angles. Again, this conclusion was based on a small amount of data that was not fully recorded. However, the process of experience with the equipment

leading to generalizations about pendulum motion without the direct posing of a question should be noted.

5. For these students, it took 15 to 20 minutes to progress from questions of social, environmental relevance to testable questions and actions that gave answers to the questions. It is possible that the “real questions” the students had were those that were not answered through the approach of experimenting with the pendulum.
6. The ability to measure time and add washers led to a question about time and washers. Students experimented with what they could measure, instead of posing a question and then figuring out what measurements would help get the answer.

Appendix G Full list of Questions (not edited for spelling or grammar)

Group 1

Introductory Questions

Student 1	Student 2	Student 3	Student 4
What is a pengulum used for? What can it be made out of? Why is there a paper clip attached? Why does it move back and forth?	What can a penjelum do? Can a penjelen help our daily lives? Do most people use a penjelum but don't know it?	Can pendulum motion involve the earth movement if you make it big enough?	How does the pendulum work? What do you use? Why is there a paper clip at the bottom? Why is there a loop at the bottom?

Oral questions from all group members after the introductory questions to the 8 minute mark

What is a pendulum?

How many (questions) did you guys have?

Should we record our questions?

Should we write down our materials and what we have?

Which order? (do we write the materials down in)

What is this?

Are we supposed to put weight on it and swing it back and forth?

Wait – how long was it? (time)

How long was it? (time) (other student repeats question)

How long(is the time to stop swinging)?

Written questions per student at the approximate 8 minute mark

Student 1	Student 2	Student 3	Student 4
none	How long can it swing with a certain amount of weight? What do most people use it for?	none	When you have more Washers (does the time get bigger?) How does a penjelim help in science?

Oral questions by the group from approximately 8-16 minutes

When you have one washer?.....

Get it? (student A has shown student B how to place a washer over a paper clip)
 Can I do four? (washers)
 Should we measure how long the string is?
 What are we going to use this thing for?
 Wait can you (we) write down how far?
 3 foot long is a yard right?
 Are those like centimeters or something?
 Would it be like 60?
 Should we have our (inaudible)? Perhaps calculator
 It doesn't go in evenly does it?
 Are we done? (measuring)
 Mrs. B, are those centimeters?
 Can I do this?
 Wait – how many washers did you get?
 Ok – how many did you get?
 (Are you) ready? (to start)
 Ready?
 What? (is the time)
 What was it?
 That was with 4 washers?
 Wait – how many washers have we used so far?
 Wait – how long?

Written questions at the approximately 17 minute mark

S1	S2	S3	S4
Why is the time different with more or less washers on the pendulum? What is the pendulum made out of?	no ne	There is something wrong with this experiment, the hypothesis would be wrong if we didn't do this (????) We need to swing at the same beginning	The washer is very interesting because when it gets more it (does it) swings longer (?)

Oral questions from 17 to 29 minutes

Where's our data?
 Can I do the next stopwatch after you?
 Can I do it?
 Mrs B – what is this (study) about?
 Does it tell you about your grade?
 Is he from the university?
 Wait – what's 59...?

Why do we even have a protractor if we are not using it?

It's two thirty always – right?

Ready?

Ready?

Should we do another experiment for fun?

Repeated

What if we go like that?

What if we try different? (actions)

So where did we leave off?

What do you think is gonna happen?

What did you put on there? (a protractor)

OK – Can I try this?

Wait – what is that thing called?

Can I do it after you?

Written questions at the roughly 29 minute time

S1	S2	S3	S4
How did it get its name?	How did it get its name? Why do people need to use them? How many angles does it have? If you make it swing in a circle will it go back to going back and forth? Did people use pendulums in the olden days?	How did it get its name? What is their main use? How many angles does it have?	What do people use them for? How did it get its name? How many angles does it have?

Oral questions up to the end

Yeah, like how did it get its name?

Why does it go at different angles?

How many angles does it have? (these refer to planes of oscillation)

Have you ever seen one of this things with 5 balls?

Is that your pencil case?

I wonder what would happen if you lined them up?

Final written comments and questions

S1	S2	S3	S4
I think pendulums only go side to side because of the vibrations that the weight of the items have on the pendulum	The more weight on the string the longer it will swing	A lot	None

Group 2 Questions

Introductory Questions

S1	S2	S3	S4
What can it be used for?	Is the washer meant to hang from the pendulum?	What can it do? What is it?	What is it? What can it do? What are we going to use it for? Why are we using it? How does it work?

Oral questions from after the introductory written questions to the 8 minute mark

What do you think it is?

What is the difference between those who signed the sheet and others?

If we find the answers can we write them down?

Do you know what it is?

Ok what can it do?

What are we going to use it for?

Why are we using it?

How does it work?

If we have two will it go quicker than if we have one?

Is the washer meant to hang from the pendulum?

Let's see how long it goes?

What is it?

Other repeats

Are we supposed to do this?

How do we write 41 times back and forth with one washer?

Should we be writing down stuff that we've figured out?

What did you write?

Written questions at the 8 minute writing mark

S1	S2	S3	S4
Does it swing more when more washers are added?	With more weight does the pendulum move quicker?	How many times will it go back and forth with 2 washers?	How many times will two washers go back and forth?

Oral questions from roughly 9 to 17 minutes

How long does it take? – Is that our question?
 What did you do that for?
 Why do we need the stopwatch?
 Everybody have it down?
 I wrote “How many?”
 So how many?
 What’s 2 washers guys?
 Is that what we figured out? (More washers makes it go slower)
 What’s 4 washers?
 OK so was that experiment?
 Do you know how to use a stopwatch?

Written questions at the approximate 18 minute mark

S1	S2	S3	S4
How many times will it swing in one minute?	none	Hypothesis - It will get faster if you add a washer How many laps can one washer do in one minute?	How many seconds will it take 5 back and forth? How many laps can 1 washer go back and forth?

Oral questions from time 19 minutes to time 27 minutes

OK – experiment 2 – right?
 Ready?
 Are you guys ready?
 Ready?
 That’s how many washers?
 Is that 2 or 1?
 Wait – was that in a minute?
 What were you doing were you finding an average?
 How many is it?

Written questions at the roughly 27 minute mark

S1	S2	S3	S4
none	None	none	How many laps can two washers go back and forth in a minute?

Remaining oral questions
 How many was it?
 Again?

How come he gets to use that thing?

Do you want it?

Ready?

Anybody have any ideas now?

Now what do we do?

What is our next experiment?

Written comments at the very end

S1	S2	S3	S4
<p>It takes 1.245 seconds for the pendulum to swing back and forth with one washer</p> <p>Adding the washer makes the pendulum swing slower</p> <p>The pendulum can swing 37 laps in one minute with one washer</p> <p>The number of laps goes down almost every time we add a washer</p>	<p>I learned that in experiment 2 when you add a washer it pretty much takes one lap</p>	<p>I learned that penjulums swing back and forth</p>	<p>I learned that in experiment 1 adding a washer makes it go slower. I alos learned in experiment 2 every washer you add it goes one less lap in a minute most of the time</p>

Group 3

Introductory written Questions

S1	S2	S3
What does a pendulum do? What are we going to do? Are we going to use any other things?	What are we going to do?	How does a pendulum work? How long is the standing?

Oral questions after the introductory written questions but before the 8 minute mark

What do you mean by measure?

How long...?

Tell me when to go?

Ready?

Is this ok?

Can you use (wrist watch)?

My hypothesis is one minute

How long was that?

Written questions at the 8 minute interval

S1	S2	S3
none	none	None

Oral questions from the roughly 8 minute to roughly 16 minute mark

Ready?

What are you student 1?

What are we supposed to be doing right now?

My hypothesis is 1 minute – What's your hypothesis, Will?

Can I do the stopwatch please?

How?

What exact second is it at?

4 minutes and what Will? Will?

Ready?

Did anyone not raise hand?

Written questions at the roughly 16 minute mark

S1	S2	S3
How long will this washer go?	none	None

Oral questions from roughly 17 minutes to 25 minutes

Are you guys ready?

I'll put it at 90 degrees, I wonder how long it will go?

We're trying to find out why it goes so long?

Yea, I asked how long will this washer go?

Let's find out why?

Why did you guess 3 minutes 48?

Hey, how come right now its at 1 minute already?

What's it at now?

What if this goes the same?

Are you ready to hold that up?

Ready?

Written questions at the roughly 25 minute mark

S1	S2	S3
Why does it go so long?	none	None

Oral questions from roughly 26 to 34 minutes

Guys what's your hypothesis for this one gonna be?

Nico, what's your estimation?

Are you guys ready to go?

Ok guys, ready?

Did I win? Will

Wait, what did Nico predict?

Why do we keep on switching pens?

Should we do something else?

Why did you guess that?

Written questions at the 35 minute mark

None

Oral questions over the last few minutes

New idea – How far does the washer go?

Should we start a new experiment now?

That was 37 minuts? (time went fast)

The three students were given the opportunity to write down what they had learned – no written comments were produced

Group 4

Introductory written questions

S1	S2	S3	S4
What does a pendulum do? What is a penjalum for? Why do we need safety glasses?	What does a penjelim do? What is a pengelum purpose? Why do we have goggles?	What is a pendulum?	What is a pendulum used for? When was it made? How do you make it go faster? Why do we need goggles? How long is the line?

Oral questions from after the introductory written questions to the 8 minute mark

How do you spell pendulum?
 Why do we need safety goggles?
 Is that thing recording?
 Should we listen to it now? (recorder)
 How do you make it stop?
 Why am I here?
 I wanna know how this works?
 Is it on now?
 Is that a magnet?

Written questions at the 8 minute mark

S1	S2	S3	S4
none	How long does it take it to go 5 times?	Does it go faster when it has more weight?	How long does it take to go 5 times? Does it go faster when it has more weight?

Oral questions from the 9 to 16 minute mark

How big is a miniature?
 All around the world?
 What are we gonna do?
 Do you guys think it goes faster when it has more weight?
 Are we gonna blow up?
 Do you guys think it goes faster when It has more weight?

How many times?
 Isn't it 2?
 These are called washers, right?
 How long was it?

Written questions at the 18 minute mark

S1	S2	S3	S4
none	More weight?	none	None

Oral questions from 19 to 28 minutes

How many weights?
 Mrs B – are we going outside for break?
 My hypothesis – Does it take longer with more weights added?
 Now which one?

Written Questions at the 27 minute mark

S1	S2	S3	S4
none	How fast would it go with 3 washers?	none	None

Oral questions until the end

Is it at 9?
 Now which one?

Comments at the end about what was learned

S1	S2	S3	S4
I learned that it take longer with all the weight than with two weights	A pendulum swings side to side like a shark	Does it go faster with more weight?	Penjalums go side to side like a shark

Group 5

Introductory Questions

S1	S2	S3	S4
Why a peng olim?	How far can a pendulum swing with one push?	Will the pendulum swing differently if we put weight on it? If we take the paperclip tied to the string and make it flat, would it change how it swings? How do you work the recorder? Will the pendulum swing faster with weights on it?	Where did the name pendulum come from?

Oral questions up to the three minute mark

Why are we using a pendulum?
A pendulum swings for hypnosis doesn't it?
Isn't it used for hypnosis?
I wonder how many times it will go?
Should I let it go?

Written questions at the first writing break

S1	S2	S3	S4
none	How long Can it swing For?	How much time does it take to reach this #? (# of swings in trial)	How long can it keep going?

Oral questions from the 5 to 14 minute mark

How many times did you get?
Is this a timer?
Ready?
How many seconds?
About 1 second to what?
Like 40 seconds would you say?
What time is it at now?
Can you?
Wait, Can I see it?
What's the done time?
Ready?
Let's see how long I can hold my breath? Ready set go.

How do you start it?
 Why do you have to plug your nose?
 I'm going to see how long its going to go?
 Why is it going so short?
 Ready?
 Wait, it was 25 seconds?
 OK – Ready?

Written questions at the 15 minute mark

S1	S2	S3	S4
How long will it go with 5 washers?	How long can it swing with no weights?	How many washers can the paper clip hold?	none

Oral questions from 15 to 24 minutes

Can I measure it next?
 What time is it?
 What was the time?
 Who keeps on hitting the board?
 So we need 4 washers right?
 So it's going to be 4 washers?
 How long is this rope?
 What?
 Can I be the timer?
 Who has the timer?
 Why?
 Do you want to know?
 Where did they put hot water?

Written questions at the 25 minute mark

None

Final questions

Is that something you learned?

Final comments and questions after experiment

S1	S2	S3	S4
<p>It uses wait and force to rock back and forth it does certain things at certain angles</p>	<p>I learned that a pengilum is an object that swings back and forth. I realized that different objects on it ment different swings and longer and faster swings</p>	<p>Each color of a pen makes a different stage of thought and testing the experiment. I, student 3 gin all rights for anyone to use this paper. A pengulum rocks back and forth. This penjulum has a green paperclip on the end. Some penjulums paperclips fell off. I used a ruler to measure a penjulem. You can put a lot of things on the end of your penjulum. 1 penjulum washer swings each time for 8 minutes per round (357 time?). I have learned that putting weights on the end of a penjelum makes the pengulum swing longer. Each swing is about one second each, 2 for round trip. Holding the end of the pengelum higher makes it go longer. Saftey goggles are essential for safety reasons</p>	<p>The weight of the swinging object can effect the wieght of the bigger object.</p>

Group 6

Oral questions before the first writing interval

Maybe you need to put your glasses on under your goggles?
How do you wear these?

Introductory Written Questions

S1	S2	S3	S4	S5
What does it have to do as part of the environment? Why is it important? Is it important? What is it used for? Why does it look like an IV Why are there washers on the paperclip?	What does it do? Can you make it yourself? What happens when it starts moving? What is it used for? What do the washers do What does it do on earth?	What is pengalim motion? What are the effects of pengalim motion? Does pengalim motion help our lives? Does it help our environment? What is it used for?	What do the washers do? What is pengulim motion? What is it supposed to do? What is it used for?	What is pengalim motion? What is it supposed to do? What is it used for?

Questions after the introductory written questions up to the first writing interval

What do the washers do?
 What is pendulum motion?
 What does it have to do?
 Can you make it yourself?
 What is it used for?
 Why does it move?
 Why does it look like an IV?
 Why is there a paper clip?
 What does it become?
 What does it have to do with the environment?
 Why are washers used?
 (The students read off their written questions or adaptation of their written questions)

Written questions at the first writing interval at roughly the 8 minute mark

S1	S2	S3	S4	S5
None	Is it going to Spin?	None	None	None

Oral questions from the 8 to 16 minute mark

What did we learn?

What is this?

Guys – are you ready to do this with a stopwatch?

Will you start it?

You wanna start it?

Why are we wearing goggles?

Maybe we will do an angle?

Written questions at the 18 minute writing interval

S1	S2	S3	S4	S5
(Why is it the case that-is it the case that) As it gets heavier it doesn't swing in a straight line and goes crazy Does weight have an effect on which direction it swings?	Does it need a middle pole?	None	None	None

Oral questions from the 19 to the 27 minute mark

Wait – can I use that big washer for a second?

What if we just time how long it goes?

What if it goes in an oval?

What?

What if we start it at an angle?

Can we see what is happening to it?

Written comments at the 28 minute writing interval

None

Remaining oral questions up to the concluding writing interval

What did you get now?

Ready?

Ready?

How many seconds?
Why is it halfway done?

Concluding comments about what was learned

S1	S2	S3	S4	S5
I learned that more wight on a swing effects the direction	I learned	When you do 5 washers it doesn't swing as far and goes a little slower and after 5 washers Hannah swung it - the string really had and the paper clip, the washers fell off and the string untied	I learned about how the string moves based on how many washers are on	When you put the washer on the string it goes 4 hundredths of a second faster than on the paper clip. In 50 seconds it can swing back and forth 40 times

Final oral questions

What is the time Hannah?
Let's see how long it takes?

Appendix H Sample Transcript (not edited)

Group 2 Class

T we are gonna start in just a second, here is what your gonna do, just leave the recorder in the center

T in this room for the next one minute, it will be completely quiet and in the upper left of your sheet use your blue pen and write down whatever questions you have, quietly, without talking to your neighbor, what kinds of questions you have about pendulum motion and about this thing swinging back and forth and about whatever is in your mind, just write that down

A bunch of inaudible noise

T just work on your own and now you can begin

S I don't really have any questions because I don't know what were doing

T let me explain that, you guys as in your case a group of three, you will decide what you want to do, you will decide what you want to learn about pendulum motion and you will use your questions to help you decide that, so go ahead

S so what do you think it is? S I think its supposed to like hang, s do we write down the answers or no?

S no I don't think so, S what is the difference between us like the people who had to sign the sheet and everybody else? T your getting video taped inaudible S ok

S our paperclip just fell off

T I will be happy to put that back on and in the future your welcome to kind of just say yeah I better do this or I better do that and just kind of take charge of it and just decide what you want to do ok?

Inaudible noises from multiple sources

S do you know what it is? S I think its supposed to hang a washer S yeah but its meant to do something

S what could it be used for? S what can it do?

S well if you put a weight on it, its starting to move more, maybe its something to show us

S what do we use it for? S its supposed to show us something S why are we using it? And how does it work? S lets see if we have two on there would it go quicker than with one?

S what is it? What can it do? What can we use it for? Why are we using it? And how does it work?

S is the washer mean to hang from the pendulum S the pendulum looks like a... S your supposed to be asking questions

S im gonna try adding another washer and see what happens S lets take the second one off

S count how long it goes...inaudible sources...

S lets count how long it will go, one, two, three... S no no no back and forth is one time

S one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty, twenty-one, twenty-two, twenty-three. Twenty-four, twenty-five, twenty-six, twenty-seven, twenty-eight, twenty-nine,

thirty, thirty-one, thirty-two, 33,34,35,36,37,38,39,40,41 S ok so forty one! It slowed down

S so what do we write? S it went back and forth 41 times with only one washer, yes murmur of agreement

S should we be writing down stuff weve figured out?

T quiet, thanks for all your interesting work that your doing, I really appreciate all of the good ideas you have shown out there. Right now Ms. Radmacher and I are going to go around and we are going to gather your blue pens, then we grab a green pen and at this point now with your green pens its ok if you shift mid sentence or something I want you to write the following information down: write down some questions that you have over the last eight minutes and write down any questions that you have right now and keep using the green pen to take data and make notes, record information and so on about what your learning during this next eight minutes, you don't have to start a whole new thing with your equipment or anything like that you can keep doing the investigation your continuing to work on, right now for just a little less than minute quietly write down questions and thoughts you have, quick questions

Inaudible noise from many different sources

T so write down questions and thoughts that you have

T I would also like to use those big sheets to write down numbers, information, ideas that you have as you get with a stopwatch

S oh shoot, we should have used the stopwatch... inaudible

Inaudible... S to make it easier for us, what were gonna do is we will let it go and then when it stops, I will stop the stopwatch, we will write it down and then we will add two washers.

S we will see if it keeps getting higher or lower or whatever

S 3,2,1 go, S how long does it take S our next one will be how many seconds

S somebody write this down S wait what did you do that for... inaudible... S you have to write this down one minute and one second and twenty five milliseconds S wait we already have that, S but yeah were doing it this way, so we can do it quicker

S inaudible...

T ok students, thanks for all your good ideas, im just gonna nudge you a little bit in the direction, write down the information your getting as you go along on your paper ok?

S two washers equal one second and 31 milliseconds S no just start the timer until it stops, just do it just do it,

S that's gonna take too much time and im not gonna be able to finish S does everybody have it down?

Murmur of agreement "yep"

S one second and 34 milliseconds for 3 washers... inaudible

S two washers equals one second and 25 milliseconds S esme you have two right? S yes, S whats two?

S im just gonna leave this here even though we don't need it

T were gonna ask that for the most part you keep your goggles on S murmur of agreement "ok"

S for three washers its one second and 34 milliseconds, S its starting to get slower S one second and 34? S yeah

S now we have four... S four washers equals how many? S that's what were doing right now.

S one second and 53 milliseconds,murmur of agreement between students "yeah"

T im going to trade you a purple for a green

S one washer equals 1.25 seconds, two washers equals 1.31 seconds, three washers equals 1.34 seconds, and four washers equals 1.53 seconds and one washer equals forty one swings back and forth S murmur of agreement of "yeah"

Inaudible....

T thank you

S oohhh purple, S its so hard to get this thing off, S see if you can get the washers off

Inaudible.....

S we have our final one, S no not yet

S inaudible..... five washers equals S equals one minute sixty two seconds, one second and sixty two milliseconds, S you know you can just say 1.62 seconds... yeah, murmur of agreement

S so we are finished with this experiment.... Inaudible....

S adding a washer makes it slower, that the hypothesis, S that's not the hypothesis

S can you give me the information now?

S adding a washer makes it go slower....inaudible....

S this is all my evidence and that's what I figured out and these all are my questions

S inaudible.....

S circle like this and write experiment one

S inaudible..... experiment one; S one washer equals 1.25 seconds, two washers equals 1.31 seconds, three washers equals 1.34 seconds, and four washers equals 1.53 seconds and one washer equals forty one swings back and forth S murmur of agreement of "yeah"

S so what we figured out is that adding a washer makes it go slower,

S I think what we should do now is see how many laps it can do in one minute.

S murmur of agreement "yeah" ,do you know how to use a stop watch, its kind of confusing, so once you get to lets say fifty seconds, no no, one minute, S you guys count and I will stop it at one minute

S experiment two right? Inaudible noises for multiple sources...

T ok you guys were just gonna ask that we be quiet, three snaps, boom boom boom, raise your hands if you are getting some interesting information, thank you. Now I want you to spend one quiet minute writing any more information and questions down quietly without talking. I really encourage you to spend this one minute.

T and S inaudible...

S he said you can write information and questions, this is information, are we ready to start?

S go! S all together counting

T ok everybody you can continue on, trade your red pen for a purple pen, thank you.

S we will do experiment two with the red pen.... Inaudible S im just taking down our questions.

S are you guys ready? S inaudible... S tell me when to go... all 3 S counting.....1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37

S 37 one washer equals 37 back and forth in a minute S 37 laps in a minute, S we should do it again just to verify, S we will do it at the end S If we have time

S you guys ready? S so is this two washers? S yes, S and go... inaudible...

All S counting together,
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36

S Oh, 36 S that one less

Lots of inaudible noise...

S wait was that in a minute? S yeah

S we got three washers, go...

S 1,2,3,4,5,6,7.. wait lets restart this...

S inaudible... S
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35

S 35! T there is your orange pen

S how many is it? S 35

Inaudible..... S everytime we add a washer, it goes down a second, it goes one less lap

Inaudible... S go, 4 washers, go.... Multiple S counting...
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34...

S 35, S I think it was like in the middle, like 34.5, S no lets just do 35

S inaudible... S how many was it? S it was 35 S it was like in the middle so we rounded it to 35

Inaudible noise....

S 3,2,1 go 1,2,3, T interrupting just after your done collecting this data take a minute to write down this stuff S agreement ok 4,5,6,7,8,9, lets restart this

S inaudible...

S 3,2,1 go
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34... 34

S it pretty much goes down by one at a time, because we were like in the middle

S inaudible... S does anybody have any ideas now? S so what do we do? S we wrote down our conclusion

S im not doing any conclusions im just writing down my data

S it pretty much goes down every washer

S I get to use the stopwatch, S whats a new experiment?

T I really need your attention this time, please raise your hand if you can see me and your able to hear me, ok? Now this next few minutes is going to be a little different, what I want you to do for the next couple minutes is move to a slightly new space on your sheet, use your black pen and write down what you learned today about pendulums and further

questions that you have. Your going to take a few minutes on this, this is the time to write, this is the time to write.

Inaudible noise....

T ok people, thanks for that writing, im going to give another three or four minutes to finish up and make sure you keep your goggles on the rest of the way, you might have a little more information your trying to get and maybe about four minutes or so and you will clean up and head back to your classes.

S I have another idea for an experiment S we cant do one now, so this one would be how far does the washer go, so we would have our stick and see how far it would go S is this yards or inches? S well yards or inches... inaudible....

S can we start another experiment? T no I think we can start cleaning up

S im writing what I learned

Group 2 interview

T when I look at your papers I see that I am able to read all the different things for you two students pretty easily so thank you for that

T I also noticed that when I watched you in action you did many things, oh lets try this, lets try this, but you didn't necessarily write that stuff down all the time. That's ok and I was just wondering looking at S1 sheet here you did write some interesting things down, what did you learn from what you wrote down?

T anybody... S well I learned in experiment 1 we figured out how long it took for like the washer to do a lap thing, and then we did all the way to 5 washers way, what we figured out was adding a washer it goes slower and slower.

T adding a washer makes the time per lap a little more S yeah

S in experment 2 we figured out how many laps it did in one minute we did that for each washer and pretty much everytime it just went down one lap expect for one time, one time is like 34-35 34-35 and others it was 37,36,35,34 so it pretty much went down a lap.

T are the results of that second experiment consistent with the results of the first experiment?

S yeah, cause adding more weight makes it slower

T So, great, im going to try it ok, so I will do one and you can write it out, ok so lets try again that didn't work S are we doing the one for a minute? T yes, lets do the one for a minute, GO All S counting 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20 S so we usually stop if it hits

T alright so lets try again S and go ALL S counting 1,2,3,4,5,6,7,8,9,10,11,12,13 uh it did it again

T so its doing the same thing doesn't it S I think its too close S yeah this thing is a lot lower than it was, we had trouble from it hitting the table T alright, so

S this is how it was, its just the string went a lot lower, S murmur of agreement

T do you think that would affect the time? S yeah, I don't think it would affect time, I think it would affect hitting it

ALL S counting again

1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40, T stop, we got to 40. S ours was 37

T so now what we want to do it is keep double checking your question, so what should we do next?

S find the average? T well we want to keep double checking how adding washers affects the time to do number of laps in 60 seconds, so what should we do? S add another washer and check it again

T I noticed that you unraveled it once, S oh yeah cause it was longer when we did it.

T here we go ALL S counting

1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40 T ok stop S so it did go down one.

T yesterday what did you get for two washers S agreement 36 one less,

T would you like to try one more S I think we have it S I think we should try one more

T looking at this data and I will put it right in front of you here I have yesterday and today, one washer, two washers, yesterday was 37 and 36, today was 41 and 39, does that give you any ideas for something else you would like to investigate?

S um, how long it goes, because like some of the laps were like really short and some were like really long S when it was with one it would go like that

T can you frame that in a way that we could actually do something to check your idea, I like your idea, so what should we actually do, why don't you give her orders and have her do something that gets to your question

S we could have one in the middle and then measure where it goes to on each side...inaudible

T so by how long the laps are you talking about distance. The distance travelled by the washers, and what do you think happens to that distance?

S its gonna get shorter and shorter T ok, so um should we check that? S how many washers?

S so lets start it at thirty and see how long it goes til...inaudible...

S so one washer and start at thirty.... Inaudible...

T if you were gonna make a chart you could make a chart kind of like this couldn't you, alright and then we would just write down how far it was on the first swing, how far it was on the second swing, does that make sense?

T you read them off, S oh ok

S first swing starts at 35 and it goes to 1- 32 2-33 3-29 4-28 5-27 6-25 T ok, so whats happening there?

S its decreasing T ok, I will just kind of let you pretend that its yesterday and im not here, keep talking to each other about that ok

S we think it decreases by like one inch every time on each side S murmur of agreement

S so like from inaudible.... S its like decreasing

T so can you suggest a method that would be even more precise to get at that information?

S like stop it, but..inaudible... T wait a minute, lets try what she said, so she says stop it, could you stop it and then let it go again? S murmur of agreement yeah T why don't you try that

Inaudible noise...

S it still decreases, its doesn't matter if you go like this and then you stop and go back up, but if you just let go

T if you tried to do that without changing things what would happen to your catching points?

S you would have to keep moving it T why don't you just sort of do that and see what happens

Inaudible....

S I think it decreases it faster T ok S inaudible...

T so what kind of obstacles or problems that you encounter as you did your experiments?

S it kept on hitting the table T ok S but I know how to fix that

T what other questions would you like to investigate?

S I wanted to know what you use this for other than testing?

T you use it for keeping time, because it keeps a regular time, you use it for studying motion because it turns out that if you know how much time it takes it to go you can figure out the acceleration to the gravity, you can use it to destroy things, like buildings when there tearing down a building sometimes they have that come in, you can use it to study motion in other ways. I will show you one way you can use it to study motion. Lets suppose you have your little sister on the swing here and your job she says alright please push me, and then here she goes.

T so when would you push her? S when she comes back to you. T ok so show me that S if you go like this then it makes it go higher, and if you go like this it inaudible.... Then she would probably end up like falling out and she did fall off

T at what point, lets say it took it six seconds to go back and forth, how often would you push if it was a five washer kid how often would you push? S every 1.62 seconds T ok

T why do you think yesterdays numbers here and todays numbers are different?

S like when we were doing it, it was up there and we just unraveled it more, so by up there and unraveling, T what characteristic did that change? S that it was lower to the ground, I don't know if that would have an affect

T what other variables might have changed? What other thing about this pendulum from yesterday to today? S well it could be like different one and it could be a different washer, so it could be different weight

T im gonna exaggerate here, lets do the trial again S inaudible.... S its looks like a doughnut on a string

S your luring the doughnut to the chipmunk S to try to catch it

T lets do that one minute thing again ok? Are you ready?

ALL S laughing.... T so not quite so high, here we go, ready, go

ALL S counting

1,2,3,4,5,6,7,8,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62

,63 T stop S 63 seconds S I think it was the height, the height can be different S no but we had it all the way up and unraveled,

T so height? How far above the ground? S well if its closer to the top if it's a shorter string T so you measured the length that matters with this? T how close it is to the ground S inaudible....

T do you think this length here matters? S yes I think it does because if its just shorter string it will move faster because its more inaudible...

T well we could go on and on couldn't we? S We could S inaudible... T so what could you do to investigate that? S I don't know...

T so we end up with more questions than answers at this point and I really appreciate all the time you took

Appendix I Sample Student Question Sheet

Group 2 Student 1 ✓

What can it be used for?

Does it swing more when more washers are added?

1 washer ~~takes~~ takes 1.25 seconds to swing back and forth.

2 washers = 1.31

3 washers = 1.34

4 washers = 1.53

5 washers = 1.62

~~It is getting~~ Adding a washer makes the pendulum swing slower.

How many times will it swing in one minute?

37 laps in 1 minute with 1 washer.

36 laps in 1 minute with 2 washers.

35 laps in 1 minute with 3 washers.

35 laps in 1 minute with 4 washers.

34 laps in ~~1~~ 1 minute with 5 washers.The number of laps goes down ^{almost} every time we add a washer.

I have learned:

1. It takes 1.25 seconds for the pendulum to swing back and forth with one washer.
2. Adding a washer makes the pendulum swing slower.
3. The pendulum can swing 37 laps in one minute with one washer.
4. The number of laps goes down almost every time we add a washer.