AN ABSTRACT OF THE DISSERTATION OF

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Scientific inquiry in K-12 classrooms tends to be procedural, lacking opportunities for students to gain understanding of how scientific knowledge is constructed through reflection, debate, and argument. Limited opportunity to develop scientific argumentation skills prevents students from practicing the scientific thinking needed to understand the nature of scientific knowledge and the role of scientific inquiry. To solve this problem in science education, recent research has focused on how to support student opportunities to learn scientific argumentation in the context of learning science content.

The purpose of this investigation was to examine and analyze one science teacher's understanding of scientific argumentation and his teaching strategies for developing students' argumentation skills in the classroom. This investigation also analyzed student discourse in response to those teaching strategies, to see how students demonstrate improved scientific thinking skills while they developed skills in scientific argumentation.

One science teacher, Mr. Field, and his students at the middle school level participated in this study for two months. Three interviews employing semi-structured protocols were used to examine Mr. Field's understanding of scientific argumentation. A structured observational protocol enhanced with field notes and audio tape recordings were employed to investigate Mr. Field's teaching strategies that led students to demonstrate scientific thinking skills. Transcriptions of student discourse and two lab reports were also analyzed for the quality of students' scientific thinking skills. Three different tools for argument analysis, *Toulmin, Epistemic Operation,* and *Reasoning Complexity,* were used to examine

student argumentation in detail.

The teacher, Mr. Field, defined scientific inquiry as the combination of developing procedural skills through hands-on activities and reasoning skills through argumentation. Seven different teaching strategies emerged based on sixty hours of classroom observation. *Daily Science* and the *Claim-Evidence Approach* were the two main teaching strategies that gave students opportunities to demonstrate the reasoning skills needed to construct scientific knowledge. However, students developed *less extended arguments* during *Daily Science*, whose purpose was to provide them with a chance to practice basic skills, such as differentiating independent variables from dependent. On the other hand, students developed *more extended arguments* during the *Claim-Evidence Approach,* where the purpose was to provide students with opportunities to develop claims, to find evidence from experiments to support the claims or refute those of others, and to discuss the limitation of the experiments.

The *less extended argumentation* observed during these activities is described as a linear flow, moving from Mr. Field's question to students' answers to Mr. Field's evaluation at the end. The *more extended argumentation* can be described as a circular flow, moving from Mr. Field's question, to students' answers, to Mr. Field's evaluation with more prompts or questions, to students' responses as justification, to Mr. Field's general explanation based on students' justification, and finally to the teacher's or students' synthesis or applications. The former argumentation is named *Fundamental Argumentation* and the latter *Exploring Argumentation*. *Fundamental Argumentation* occurred more often than the other during this study. Shifting from *Fundamental Argumentation* to *Exploring Argumentation* was observed to depend on the teacher's scaffolding, such as using more extended questions and prompts to further the discussion.

In addition, the students' abilities to develop scientific argumentation were related to their scientific knowledge, the teacher's engagement in interacting with students, and the opportunities students had to practice scientific argumentation. Limited scientific knowledge is believed to prevent students from demonstrating reasoning skills. Also, "wait time" that students need to retrieve knowledge, described by Mr. Field, is also believed to be one of the barriers to scientific argumentation in some of Mr. Field's classroom interaction. Further investigation of students' abilities to develop scientific argumentation in different contexts, such as group work and whole class discussion, is recommended with the use of the argument analysis tools employed in this study, in order to better understand the nature of learning and teaching scientific argumentation in the classroom.

Analyzing Explicit Teaching Strategies and Student Discourse for Scientific Argumentation

by

Young-Shin Park

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Young-Shin Park, Author

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CHAPTER I

THE PROBLEM

Introduction

Scientific inquiry in K-12 classrooms tends to be procedural, denying students the opportunity to understand how scientific knowledge is constructed through reflection, debate, and argument (Gallagher & Tobin, 1987). Furthermore, limited opportunity to practice scientific argumentation prevents students from gaining the scientific thinking skills needed to understand the nature of scientific knowledge and the role of scientific inquiry. Science education reformers argue that scientific literacy has become a necessity for everyone. The view is that everyone needs to use scientific information to make choices that arise every day. To promote scientific literacy, the *National Science Education Standards* (National Research Council [NRC], 1996, 2000) outline what students need to know, understand, and be able to do to be scientifically literate, based on an understanding of how scientists construct new knowledge through scientific inquiry. Developing skills in analyzing points of view and critiquing scientific work is at the core of achieving reform objectives (Champagne, Kouba, & Hurley, 2000). To solve this problem, recent research has focused on how to support student opportunities to learn scientific argumentation in the context of learning science content.

Scientific Inquiry

Scientific inquiry is one way that scientists build new scientific knowledge. Reformers recommend that students need to have opportunities to experience scientific inquiry in order to understand how scientists construct new knowledge. Instruction in this process involves students making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results as scientists do to investigate natural phenomena (NRC, 1996, p. 23). The content standards for teaching science as inquiry include both abilities and understanding of inquiry. First, the abilities necessary to do scientific inquiry are "cognitive abilities" beyond the "process skills" of observation, inference, and experimentation. Inquiry abilities require students to mesh these processes with scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science (NRC, 2000, p. 18). Second, the *Standards* expect students to understand the nature of scientific inquiry (NRC, 1996). Understanding scientific inquiry reveals how and why scientific knowledge changes in response to new evidence, logical analysis, and modified explanations debated within a community of scientists (NRC, 2000, p. 21). During the inquiry process, students develop an understanding of how they know what they know and what evidence supports what they know.

Teaching Scientific Inquiry in the Classroom

Many studies in science education have found that many scientific inquiry practices implemented in the classroom require only low cognitive thinking processes or are just cookbook type activities without opportunities for students to truly understand and explore the nature and limitations of scientific knowledge building (Gallagher & Tobin, 1987; Krajcik et al., 1998). Gallagher and Tobin (1987) reported that inquiry process was presented as a recipe, asking students to follow steps without applying reasoning skills. Tasks required low cognitive demand for reasoning during laboratory time with the emphasis on students' completion rather than learning science as inquiry. Krajcik et al. (1998) also reported that students did not use opportunities to draw conclusions by reflecting on their data and questions. Some students in groups drew conclusions based on their experience rather than their data. Others developed research questions that were not connected to their content. This evidence suggests that teaching scientific inquiry currently focuses more on hands-on activities than on reasoning about the process and results.

The *Standards* are clear when they advise educators that scientific inquiry is not simply a hands-on activity. Getting students to understand science as inquiry requires minds-on activities such as argumentation, explanation, and communication of results as well as hands-on activities of experimentation and exploration. What is minds-on activity during scientific inquiry? Crawford (2000) described how one biology teacher implemented scientific inquiry with opportunities for student communication, which emphasized the students' reasoning skills as well as their hands-on activities. This biology teacher provided opportunities for argumentation by encouraging students to interpret the data with their own comments. Students in groups also represented the data using three different graphs, looking at how the groups were alike or different in displaying their data and using the data to support their hypotheses. Additionally, when students encountered anomalous data during their investigation, the teacher suggested that students should replicate the reliable data. Crawford, Kelly, and Brown (2000) also described how one elementary teacher created opportunities for students to engage in scientific discussions with each other, to foster their own interest, and to initiate questions so that the whole class could participate in scientific inquiry beyond teacher-led curriculum. Students were offered opportunities to use their knowledge of inquiry processes, such as posing questions, observing, and offering alternative interpretations. Students also used their social practices, such as group norms for speaking and listening and particular ways of formulating an explanation.

The evidence above suggests that minds-on activities during scientific inquiry classroom instruction intend to provide students with opportunities to understand that scientific knowledge is both socially and individually constructed. Students were encouraged to determine what would constitute evidence, to explore each explanation, and to gather evidence that either supports or refutes each explanation in turn, working critically and logically by using argumentation. In addition, students were critical of their tools and methods, reflecting on what they learned by evaluating and communicating the advantages and disadvantages of the specific models used to explain natural phenomena. With these points, teachers in Crawford (2000) and Crawford, Kelly, and Brown (2000) were considered to be successful in implementing argumentation opportunities in scientific inquiry, helping students develop an understanding of the nature of scientific inquiry as well as science concepts.

Argumentation in Science

What does student argumentation in the classroom mean? Driver, Newton, and Osborne (2000) state that argumentation is important within the social practice of science because students need to develop knowledge and understand the evaluative criteria used to establish scientific theories, which will further enhance the public understanding of science and therefore improve scientific literacy. There are four goals for argumentation in the classroom: (a) to develop students' conceptual understanding, (b) to develop investigational capability, (c) to develop an understanding of scientific epistemology, and (d) to understand the value of a social practice of argumentation with peers and teachers (Driver, Newton, & Osborne, 2000).

Kuhn stated that we should experience science as argumentation as well as science as exploration in order to understand the scientific thinking of scientists; students' scientific thinking can be developed best when they practice describing and justifying theories, presenting alternative theories, presenting counter-arguments, and providing rebuttals through argumentation with peers and teachers (Kuhn, 1986, 1993). It has been illustrated that students need to distance themselves from their own beliefs to a sufficient degree to be able to evaluate those beliefs as objects of cognition. That is, Kuhn mentioned that students should have the capacity to think about their own thought. Her concern is not that students acquire the correct experimentation strategies involved in traditional scientific hypothesis-testing, but that students develop the ability to coordinate their existing theories with new evidence they generate in an explicit and conscious way.

Vellom and Anderson (1999) investigated sixth graders' argumentation through small and whole class group work, using the concept of density as the content of the instruction. The instructional sequence started with the teacher demonstrating some phenomena using three different color solutions with different densities. In small groups, the students were then challenged to make as many different stacks as possible using the three different solutions. Finally, the teacher and students worked together to find out possible and impossible stacks of solutions with three different densities, using argumentation when the groups presented the results. All students took pre- and post-tests for conceptual understanding, and two target students participated in interviews for further analysis. The study's findings indicated that (a) through argumentation with peers and teachers, students reached one agreed-upon theory by sharing their supporting or refuting evidence from their investigation, and (b) students had opportunities to discuss experimental techniques and replication and to assess whether a particular scientific claim or fact fits into a larger pattern of data and theory. By developing argumentation with peers and teachers, every student knew which stacks were possible and which were impossible from their understanding that the stacking order depended on a property of the solutions themselves. This study showed how students learn science concepts in the context of scientific inquiry through argumentation based on their observations and experimentation.

Vellom and Anderson (1999), however, reported that inappropriate instruction by the teacher as authority made a few students unsuccessful in generating adequate standards through their discussion. For example, when the teacher introduced one stack of solutions, he attempted to control opportunities for some target students to speak more during the class discussion and imposed rules so that issues could be resolved only by class consensus.

Group Work as Social Practice for Scientific Argumentation

Then what kind of teaching strategies are effective in enhancing students' understanding of how scientific knowledge is constructed through scientific inquiry activities? A pivotal teaching strategy for teachers that provides students with the opportunity for argumentation is using small group activities with peers or teachers. Studies (e.g., Richmond & Striley, 1996) of student argumentation during scientific inquiry in the classroom have found that different types of small groups influenced students' achievement in gaining science concepts and the skills of scientific inquiry.

Richmond & Striley (1996) investigated argumentation of 24 tenth-grade students using video and audiotapes of four laboratory investigations of integrated science content over three months. They looked at how students constructed and used their developing scientific knowledge to solve problems within the context of cooperative learning, i.e., small group work. The results showed that the specific social roles and leadership styles that developed within the groups greatly influenced the ease with which students developed scientific understanding. In the early laboratory experiments, students experienced difficulties in differentiating a problem from a hypothesis, understanding the value of controls in designing experiments, and distinguishing between what they observed and what the observations meant.

As the experiments went on, the levels of engagement rose as a result of the group work and the students' arguments became more sophisticated and better situated in an intellectual context. In other words, students could formulate appropriate scientific arguments by identifying the relevant problem, collecting useful information, stating a testable hypothesis, collecting and summarizing data, and discussing the meaning of the data. In addition, three varying styles of group leadership influenced students' understanding of scientific content within a larger intellectual picture: (a) the *inclusive leader* who constructed knowledge through argumentation with other students, (b) the *persuasive leader* who mainly led argumentation in constructing knowledge, and (c) the *alienating leader* who constructed knowledge weakly. Overall, this study put emphasis on what kind of small group leader was most effective in motivating students to think scientifically and in helping students understand how scientific knowledge is constructed. The results concluded that the inclusive leader was the most effective.

Herrenkohl, Palincsar, DeWater, and Kawasaki (1999) selected 27 gifted third- and fourth-grade students and 24 regular fifth-grade students with two teachers to see how students develop and refine their explanations of floating and sinking through the process of negotiation, in order to reveal the importance of using group discourse. For this purpose, Herrenkohl et al. (1999) implemented some interventions: (a) the *tools* of predicting and theorizing, summarizing results, and relating predictions, theories, and results; (b) *specific roles* assigned to students as experimenters in small groups and as audience members in whole class presentations; (c) *question charts* to make critiques when presenting results; and (d) *theory charts* to document developing theories over time. Pre- and post-test results showed that all students improved their conceptual understanding significantly. Transcripts of students' argumentation in groups showed the importance of using small groups with specific assigned roles for students: (a) *procedural roles,* such as who collected the data, who kept time, and who collected the materials; and (b) *audience roles*, such as who predicted and theorized, who summarized results, and who related predictions and theories. This study revealed the importance of guiding students during inquiry experimentation and argumentation by assigning specified roles in order to encourage students to think scientifically and understand how scientific knowledge is constructed.

Both studies by Richmond and Striley (1996) and Herrenkohl et al. (1999) showed how effective students' specified roles in small groups were in developing their abilities to think "scientifically" and to construct scientific knowledge through argumentation with peers or teachers. It is relevant then, at this point, to define what "scientific thinking" is.

Scientific Thinking

Kuhn (1989a) claimed that the heart of *scientific thinking* is the ability to differentiate between evidence and theory and to coordinate these two appropriately to construct new knowledge. She describes a scientific thinker as someone who (a) is able to consciously articulate a theory that scientists accept, (b) knows what evidence could support the theory and what evidence could contradict it, and (c) is able to justify why the coordination of theories and evidence has led scientists to accept a theory or reject others regarding the same phenomenon (p 674). On the basis of this definition of scientific thinking, Kuhn and other researchers (Klahr & Kotovsky, 1989) investigated the process of scientific thinking and obtained results that suggest that there are significantly different thinking processes among children, lay adults, and scientists.

Kuhn, Amsel, and O'Loughlin (1988) selected third, sixth, and ninth graders, average adults, and graduate students as experts to see how those subjects used a variety of devices to bring evidence and theory into alignment when their theory and evidence were inconsistent. It was found that younger subjects were less likely than older ones to distinguish firmly between theory and evidence and less likely to be able to resolve the conflict between the two. For example, one of the studies had to do with the effects of features of a set of sports balls on the quality of a player's serve. Evidence was portrayed by the actual balls placed in baskets labeled *Good Serve* and *Bad Serve,* and the subjects were asked to relate the evidence to these two different theories. One of the third graders concluded that there was minimal and insufficient evidence. His response included that Mr. Size (differentiating *Good* or *Bad Serve* theories) would win because the ball is big and Mr. Color would lose because the color doesn't matter, even though he theorized that size was causal (with large balls for *Good Serve* and small balls for *Bad Serve*) and color was non-causal.

Dunbar and Klahr (1989) selected third to sixth graders and undergraduate students with competent computer backgrounds to find out the function of a key from a keypad based on their trial-and-error practices with a BigTrak robot, observing their abilities to coordinate the two problem spaces of *hypothesis* and *experiment.* *Hypothesis space* is guided both by prior knowledge and by experimental results. *Experiment space* is guided by the current hypothesis, and it may be used to generate information to formulate new hypotheses. Dunbar and Klahr (1989) reported that there was little difference between the children and the adults at the level of subjects' global behavior on the task. That is, both groups clearly understood the nature of the task and realized that they could only discover how the device worked by making it behave, observing that behavior, and generating a summary statement that captured the behavior in a universal and general fashion.

Dunbar and Klahr (1989) however, found that there were profound differences in the consequences of how this general orientation toward discovery was implemented. Adults had a 95% success rate, whereas 90% of the children failed. This difference was not from their procedural ability to generate informative experiments but from their reasoning and inducting ability using the results of those experiments. Children were observed to generate data to patch a faulty hypothesis or to produce an expected effect, whereas adults generated a data pattern with which they could induce a new hypothesis. Children were observed to induce new hypotheses from experiments, but none of them were able to use an experimental result to induce a new theory. Adults were largely successful in completing their job assigned, whereas children showed limited ability to coordinate the two problem spaces of hypothesis and experiment and to design informative experiments that led to successful problem solutions.

All these studies (Kuhn, Amsel, & O'Loughlin, 1988; Dunbar and Klahr, 1989; Klahr and Dunbar, 1988) reveal that scientific thinking skills essential to constructing scientific knowledge during the inquiry process are related to the skills of differentiating evidence from theory and coordinating the two together. It is also concluded that these scientific thinking skills that scientists use in their investigations of natural phenomena cannot be the same that students use in their daily life. Kuhn (1989a) stated that children are like scientists in the sense of *understanding of scientific phenomena,* which means that both child and scientist gain understanding of the world through the construction and revision of a succession of models, or paradigms, that replace one another. However, Kuhn argued that the *process of scientific thinking* to revise those models or theories is different between child and scientist. Reif and Larkin (1991) also examined students' understanding of scientific inquiry at schools. Reif and Larkin stated that students had erroneous conceptions of scientific goals, that is, they used goals and ways of thinking that were effective in everyday life but inappropriate to science, and they devised ways of thinking that were not suitable to science.

Students need to develop those scientific thinking skills, such as the ability to differentiate evidence from data, during their scientific inquiry lessons at school. Scientific thinking skills are achieved through argumentation practices regarding a certain scientific concept in the context of scientific inquiry (Duschl & Osborne, 2002). For this purpose, teachers need to provide students with opportunities to develop conceptual understanding, to develop investigative competence, and to understand the epistemology of science.

Developing Scientific Argumentation in the Classroom

Hogan, Nastasi, and Pressley (2000) investigated eighth-grade student groups' argumentation with and without a teacher's help in developing a model to explain a phenomenon. Students' accomplishments differed somewhat depending on the presence or absence of a teacher in the discussion. The teacher tended to act as a catalyst in discussions, motivating students to expand and clarify their thinking, without using direct instruction or other exposure to conceptual information. Teacher-guided discussions were a more efficient means of attaining higher levels of reasoning and higher quality explanations, but peer discussion tended to be more generative and exploratory. When students worked by themselves, they tended to initiate new avenues of discussion by making a conceptual contribution, such as sharing ideas, rather than by asking one another questions. On the other hand, when students interacted with a teacher during a given discussion, new conceptual territory was opened mainly by the teacher's direct requests for information. Most students' contributions to a discussion with the teacher's help were conceptual; the teachers' role was predominantly a questioner and the student's role was respondent in teacher-guided groups. Teachers were clearly in control of the students' discussion, but they did not dominate interactions between or among students. This evidence showed that teachers, by prompting for and clarifying ideas, created conditions that caused students to expand and clarify their own thinking.

Yerrick (2000), acting as teacher and researcher, examined the effects of open inquiry instruction with low achieving high school students with physics as the lesson content. Yerrick examined students' argumentation, which was observed to shift toward understanding the nature of scientific argumentation. After Yerrick's instruction, students offered more tentative and sophisticated answers and constructed their explanations linking evidence to warrant. Furthermore, students developed the warrant after body of evidence, which tests would produce when they were asked how they would know if they were right. For this area of learning, Yerrick required students to (a) posit a hypothesis with supporting evidence to propose models or explanations, (b) design and carry out experiments in groups of three to test their claims, and (c) discuss their models or initial claims with the whole class, which ended in one of two ways: either students agreed to accept the model or they returned to the lab for more evidence. To develop a discourse community without a teacher's authority to determine the correct answers, Yerrick promoted the notion that students' questions and experiences were to be valued first, and critique of those ideas was promoted as a subsequent necessity for communal understanding of any problem.

These two studies, Hogan, Nastasi, and Pressley (2000) and Yerrick (2000), showed how teachers' roles in scaffolding could promote students' argumentation in order to develop their scientific thinking skills during scientific inquiry activities. In the scaffolding process, teachers pose questions, not to evaluate but to discover what students already know and what ideas students are struggling with. Teachers' prompts intend to help students gain understanding rather than simply evaluate what they are learning (Pressley, Hogan, Wharton-McDonald, Mistretta, & Ettenberger, 1996).

Recent research has investigated few opportunities for students' developing scientific argumentation or opportunities of demanding low cognition to understand the nature of scientific knowledge. The research has also investigated teaching strategies that provide students with opportunities to develop argumentation skills. The research also implies that teachers can encourage students to demonstrate scientific thinking skills by providing them with opportunities for developing argumentation through instructional curriculum. However, there is little research on what kind of function or models of explicit teaching strategies teachers employ for student argumentation and how students respond to those teaching strategies. It can be assumed that the quality of student argumentation differs in response to teachers' different explicit teaching strategies.

Statement of the Problem

Recent studies about scientific inquiry emphasize the use of scientific argumentation to gain understanding of the nature of scientific knowledge based on observation and experimentation. Students need to learn how to think scientifically through argumentation, which requires the abilities to differentiate evidence from theory and to coordinate them in order to understand how scientific knowledge is constructed. How can teachers provide students with those opportunities for scientific argumentation? Studies of students' argumentation imply that educators and teachers can and need to develop pedagogy that provides students with argumentation opportunities and enhances their scientific thinking.

Herrenkohl et al. (1999) showed how students enhanced their reasoning skills as well as procedural skills in a small group context, using charts designed by the teachers. Those charts facilitated students' reasoning skills such as differentiating data from theory and coordinating them in developing explanations of phenomena. Surely, teachers' prompts and questions encouraged students to extend their thinking process to the broader science content. The teachers' scaffolding of roles for students' argumentation is not simply for the purpose of triadic dialogue consisting of the teacher's question, students' responses, and the teacher's evaluation (Lemke, 1990). With their great deal of knowledge about curriculum and individual students, teachers understand the problems that their students are experiencing and are able to generate a variety of prompts and questions that stimulate students' thinking in appropriate directions and away from misconceptions (Pressley et al., 1996).

The most important finding from studies of student argumentation is the current lack of opportunities for students to use argumentation in the science classroom. That is, there is a general lack of pedagogical expertise among science teachers in organizing activities in which students are given a voice. Therefore, it can be said that it is important to improve teachers' knowledge, awareness, and competence in managing student participation in discussion and argumentation as well as to enhance the argument skills of young people. For this purpose, it is necessary to know what kinds of teaching strategies are effective or ineffective in enhancing students' argumentation in the classroom. It is also necessary to know who provides opportunities for argumentation and in what ways these opportunities are provided. The examination about how teachers scaffold students to extend their reasoning skills as well as procedural skills for investigation, compared to others who do not, is also necessary.

Based on these theoretical frameworks, the researcher developed an interest in emerging instructional strategies that give students opportunities to use scientific reasoning during argumentation. First, this study examines the patterns or generalizable instructional strategies for argumentation implemented by teachers. What is teachers' knowledge of scientific argumentation during scientific inquiry? Is there any relationship between teachers' knowledge and their practices for students' argumentation in the classroom? What is the range of student response to teachers' explicit teaching strategies for students' scientific argumentation?

Students before the ages of 10 or 11 are known to hold incomplete scientific knowledge to do scientific inquiry (Carey, Evans, Honda, Jay, & Unger, 1989); therefore, secondary schools are appropriate for my investigation of how teachers provide opportunities for students to use argumentation to understand the nature of scientific inquiry and argumentation. The research questions that guided this investigation are as follows:

1. What is teacher's knowledge of scientific argumentation?
2. What kinds of instructional strategies are emerging when the teacher scaffolds students' argumentation?
3. How do students respond to these strategies?

Significance of the Study

This investigation is significant for practical reasons. Many teachers are not sure of how to use scaffolding to help students understand how scientific knowledge is constructed. If generalizable and exemplary instructional strategies that have enhanced students' argumentation are developed, those strategies should be documented and used as a guideline for other inservice teachers to employ in developing student argumentation. This study is a reminder that teachers serve an important role in the classroom by guiding and scaffolding ways in which knowledge gets shaped, refuted, and promoted. The practices of the teacher's role of scaffolding to promote students' thinking skills can be made explicit so that science educators can modify or apply these practices in designing their instructional curriculum to include opportunities for scientific argumentation.

Identifying exemplary instructional strategies for students' argumentation can also make a significant impact on teacher education for preservice teachers. Preservice teachers are trained to design scientific inquiry lessons with an emphasis on hands-on activities through experimentation rather than minds-on activities through argumentation. Therefore, this investigation identifying models or functions for students' argumentation during scientific inquiry can lend support to science educators in providing preservice teachers with more practical knowledge of how to create scientific inquiry environments full of argumentation.

CHAPTER II

THE LITERATURE REVIEW

Introduction

The purpose of this study is to examine the instructional strategies that science teachers can implement to allow their students to understand science as a process of inquiry through their own argumentation. Through argumentation, students understand how they construct scientific knowledge based on their observations and experiments. This chapter is a review of literature that illuminates the framework supported by this research. The review includes studies related to (a) scientific inquiry and its definition, problems with implementation, and implications for the classroom; (b) scientific argumentation and its definition and implementation in the classroom; (c) social practices of small groups; (d) scientific thinking through scientific argumentation; and (e) teachers' scaffolding instructions for using student argumentation in the classroom.

Scientific Inquiry

The goal of teaching science as inquiry in the regular classroom has a long history. In 1910, John Dewey addressed science as a subject matter and as a method. His general theme was that science teaching placed too much emphasis on the accumulation of information and not enough on science as a method of thinking and an attitude of mind.

In the late 1950s and the 1960s, Joseph Schwab published articles on teaching scientific inquiry and argued that science teachers should experience laboratory to lead the classroom phase of science teaching for students' learning. Schwab also proposed that students should engage in discussions about problems, data, the role of technology, interpretation of data, and conclusions drawn by scientists through readings, reports, or books about the research, which he called "enquiry into enquiry."

In the late 1970s and early 1980s, science education documents used the term "inquiry" both as content and as an instructional technique. The importance of teaching science as inquiry has been emphasized by encouraging habits of mind through instruction on the nature and history of science in the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) and by making inquiry central to the achievement of scientific literacy as outlined in the *National Science Education Standards* (NRC, 1996). The *Standards* use the term "inquiry" in three ways: first, as *content,* that students should understand about scientific inquiry. Second, inquiry is the *ability* that students should develop from their experiences with scientific inquiry. Inquiry is also referred to as *teaching strategies and the processes of learning* with activities of inquiry (Bybee, 2000). On the basis of this historical perspective, how can we define scientific inquiry?

The Definition of Scientific Inquiry

Scientific inquiry of scientists is different from that of students in the classroom. Reiff, Harwood, and Philipson (2002) and Ritchie and Rigano (1996) investigated scientific inquiry as understood by scientists at their research site. Reiff, Harwood, and Philipson (2002) investigated 52 scientists' understandings of scientific inquiry using semi-structured interview protocols. Through constant comparison, characteristics of scientific inquiry were identified independently, followed by a discussion by the authors bringing those categories to a consensus. As a result, the authors reported three broad areas defined as scientific inquiry from the scientists' view.

First, the investigator is *to make connections, to connect different disciplines, to focus on the process of the investigation, and to have analytical and critical thinking skills for scientific inquiry.* For an example of connecting different disciplines, one scientist in this study described how techniques used in biology or chemistry could be applied to other fields. For an example of focusing on the process, some scientists described science inquiry as not the result but the process of investigation. Second, an investigation, as the process of scientific inquiry, is the *bridge connecting the known with the unknown.* One medical scientist responded that scientific inquiry is starting with the certainty and then moving to the uncertainty. Some scientists have emphasized the importance of developing a good question to driving the investigation.

Third, the *model of the inquiry wheel* represents the process of scientific inquiry. The inquiry wheel includes the following steps: (a) making observations, (b) defining the problem, (c) forming the question, (d) investigating the unknown, (e) articulating the expectation, (f) carrying out the study, (g) interpreting the results, (h) reflecting on the results, (i) communicating with a general audience and the scientific community, and (j) questioning again. The inquiry wheel is framed with questions at the hub and a circular arrangement of stages. It is assumed that the process of scientific inquiry can begin at any stage and may be revised as often as required.

Reiff, Harwood, and Philipson (2002) concluded that all definitions by the *Standards* are supported by the characteristics captured by the model of inquiry in this study. The authors, however, have argued that the *Standards* are limited in their definitions of scientific inquiry when compared to the inquiry wheel defined by this study. For example, communication in the *Standards* is limited to reporting results without communication among the student researchers or with experts. The communication in the inquiry wheel model can occur at any time if needed. The authors implied that the inquiry wheel model could help science teachers make decisions about when and how to limit the process of scientific inquiry and could also serve as a means to determine if full inquiry has occurred. The next study, Ritchie and Rigano (1996), described how scientific inquiry takes place in the laboratory situation, by observing elite high school students working with the help of a supervisor or a technician. The study was conducted through classroom observation with field notes and interviews as the primary data sources. The authors found that students' inquiry activities at research sites were different from those at school sites.

Ritchie and Rigano (1996) reported that the two students who participated in this study developed sophisticated laboratory techniques, gained an understanding of chemical concepts, and gained ownership over their own independent research by developing inquiry skills and reasoning skills during the project. First, two student participants developed their lab techniques and conceptual understanding. At the beginning of the project, the participating students had difficulty in using the techniques and tools due to limited experience rather than skill-level. However, as the students became more competent with the lab procedures, they were progressively grasping chemical concepts beyond the school experience. This finding implied that students' laboratory technique needed to be refined before conceptual progress could be made.

Second, these two elite students dealt with their daily frustrations and compared their observed practices with descriptions of undesirable school practices, such as following the inquiry steps without opportunities for cognition. Students learned that "blind alleys" of an experimental failure provided invaluable experience essential in laboratory work. These two students as participants came to know that blind alleys and reruns were normal practice in scientific research, which made them understand the nature of the problem in the more authentic investigative conditions of the project. Third, Ritchie and Rigano (1996) described students' physical participation in experimentation. Students gained ownership and developed independence in their research through social relationships with experts. Toward the end of the project, both students were capable of setting up the apparatus and planning their after-session without consultation or supervision.

These two studies, Reiff, Harwood, and Philipson (2002) and Ritchie and Rigano (1996), showed what scientific inquiry of scientists looks like, which is called "authentic scientific inquiry." There is enough time to communicate about their experimentation with experts or colleagues, such as regarding collecting data as replication for reliable data, sharing information to find patterns based on earlier known studies, using rich context in laboratory, and getting mentors' help as scaffolding. Then, what does scientific inquiry by students in the classroom look like? The next two studies, Gallagher and Tobin (1987) and Krajcik, Blumenfeld, Marx, Bass, Fredricks, and Soloway (1998), described the limitations of implementing scientific inquiry with students in the classroom.

<u>Scientific Inquiry in the Classroom</u>

How does scientific inquiry defined by scientists look when embedded in the classroom context? The following two studies describe how scientific inquiry at school sites could be different from authentic scientific inquiry at research sites.

Gallagher and Tobin (1987) investigated the scientific activities of and interactions between 15 teachers and their students at two Western Australian high schools, to see how instructional and managerial practices affected opportunities for students' involvement in their learning science as inquiry. Data included two hundred classroom observations of lessons, written self-reports on student engagement, questionnaires from teachers, and interviews with 15 teachers and 86 students using stratified random procedure.

Gallagher and Tobin (1987) reported the findings as follows. First, science teachers equated task completion with coverage of content, viewing their job as presenting the material in the text and laboratory guide and the students' job as accepting what teachers provided passively without developing scientific thinking skills. Second, teachers and students did not clearly understand the purpose of scientific inquiry activities in the classroom. Many teachers used some scheduled laboratory time for non-laboratory instructional activities, such as reviewing for tests, introducing topics, showing films, etc. Third, demand on students' cognition during science classes and laboratories tended to be relatively low. There was more emphasis on rote memorization of factual information in classes and on conclusions in laboratories than on comprehension, application, logical reasoning, and processes of science. Furthermore, the cognitive level of work was reduced by allowing students to copy information relevant to questions and problems from the textbook or by providing students with type examples and algorithms that reduced the cognitive level of work. Fourth, most class time was devoted to five to seven more able students as target students. Most teachers defended this practice as essential to the completion of the work required by the syllabus, text, and laboratory guide. Higher order questions were asked of the target students and those questions served as the basis for instructional transitions from one concept or topic to the next.

Gallagher and Tobin (1987) concluded that nurturing the skills of inquiry, the values of science, or even understanding of scientific principles did not appear to be the teachers' intentions. Teachers did not provide a pre-lab to discuss the purposes of the activity, the procedures to be followed, and the connections between purposes and procedures. In post-laboratory activities, teachers were unable to draw meaningful conclusions based on students' collected data. Students went through the motions of gathering and recording data, but they did not comprehend the meaning of their actions or of the data. Gallagher and Tobin (1987) revealed the basic problem with scientific inquiry in a classroom context: low cognitive demand in activities or recipe procedures that don't require a reasoning process. The next study, Krajcik et al. (1998), described how students applied their reasoning process based on their experimentation as low cognitive aspect.

The purpose of this study by Krajcik et al. (1998) was to investigate the problems that students might have during their inquiry learning and then to design instructional practices to promote more effective inquiry learning. The authors first examined what middle school students do during inquiry learning and where they have difficulties. Two seventh-grade teachers and their chosen eight target students in an independent school in a small urban community participated in this study for six months. Two projects were implemented to see how students generate questions, design investigations, collect and analyze data, and interpret and present conclusions using a scientific inquiry process. Case studies of student teams, including the eight students, were developed through sixty hours of intensive classroom observations, including five interviews with each student, and artifacts such as assignments, tests, and notebooks.

Krajcik et al. (1998) reported that the students' difficulties in doing scientific inquiry activities occurred at four different steps in the inquiry process. First, students had difficulties developing research questions for inquiry investigation. Some students' questions were not rich enough to encompass the content. Second, students had difficulties in designing investigations and planning procedures for inquiry. Most groups discussed the feasibility and procedures of designs as well as the need for controls. Students did not indicate what they were looking for in the observations or how the observations would help in answering the questions. Third, students had difficulties in constructing apparatus and carrying out the inquiry procedure. Instead, students focused on phenomena that attracted their attention, like smell and mold. However, they did not consider how or whether these variables were related to the phenomena that they were investigating. Fourth, students had difficulties analyzing data and drawing conclusions and collaborating and presenting findings. Students did not draw on their organized charts or tables to help in transforming data, and most students did not articulate how they arrived at conclusions. Students did not use all of the data collected in drawing conclusions. Students presented what they did, what they collected, and what they concluded, rather than using the presentation as an opportunity to share what they learned.

Krajcik et al. (1998) concluded that students had problems with scientific inquiry in the classroom, involving low-level factual questions, superficial rather than constructive feedback, and undeveloped collaboration. The authors, however, implied that students have promising abilities to do scientific inquiry with the support of teachers' scaffolding and with enough time to control the task. For example, teachers need to give enough time for students to complete complicated procedures, to redo their work, and not to lose track of their questions and the purpose of data after a long period of work. To maintain students' motivation and interest in sustaining cognitive engagement in the investigation, teachers need to encourage students to discuss the substance of the experiment and other interesting observations.

These two studies, Gallagher and Tobin (1987) and Krajcik et al. (1998), showed how scientific inquiry of students in the classroom could be different from that of scientists at research sites, by examining the problem of scientific inquiry when implemented in classroom contexts. Overall, they found there are no opportunities for students to discuss how their inquiry experimentations were designed, developed, and carried out, or for their conclusions to be shared with peers and teachers. Students framed questions at the beginning, but there was no opportunity to talk about how those questions were testable and embedded in the content selected by the teacher.

Students collected experimental data, but they did not have the chance to talk about how those data were supportive in answering their questions. Students developed some conclusions, but they did not have a chance to evaluate or reflect on them in connection with their collected data or their research questions.

It is concluded that the potential difference between authentic scientific inquiry by scientists and school scientific inquiry by students is an "opportunity" to talk about understanding of how scientific knowledge is constructed. The next few studies showed how scientific inquiry in the classroom context can be implemented successfully with more opportunities to talk with peers and teachers.

Implementing Scientific Inquiry in the Classroom

School scientific inquiry by students is not the same as authentic scientific inquiry by scientists. Students in the classroom have not been given opportunities to understand how scientific knowledge is constructed. Instead, teachers have focused only on procedural skills of scientific inquiry. Some studies (e.g., Crawford, 2000), however, described how teachers were successful in implementing scientific inquiry with the purpose of developing students' scientific reasoning skills, by providing opportunities for students to communicate with peers and teachers so that they can understand how scientific knowledge is constructed.

Crawford (2000) examined the practices of one high school biology teacher, Jake, who was selected on the basis of his effective teaching strategies for inquiry-based lessons. Through observations, journals, and interviews, Crawford investigated the key aspects of this biology teacher's instruction, examining critical incidents that showed students' understanding of inquiry and students' roles as well as the teacher's role for creating an authentic inquiry environment in an ecology class.

Crawford developed the instructional behaviors that Jake used in the scientific inquiry lesson that created inquiry environments in which students could understand science as inquiry. First, Jake situated his instruction with real world problems by emphasizing the importance of data from the real world and communicating his own interests to his students. Second, Jake encouraged students to interpret the data with their own comments. Third, Jake fostered collaboration between students and the teacher by considering students as valued members of each research team. Fourth, Jake encouraged students to contact their own community for more data or information in their investigation. Fifth, Jake modeled the behaviors of a scientist by demonstrating how he carried out an investigation by sharing ideas or results with experts outside the classroom. Sixth, Jake fostered students' ownership by encouraging students to feel a responsibility to complete the task, motivated by the unknown results.

Jake's instructional practices of inquiry emphasized the value of students' communication with peers, teachers, and experts outside the classroom during their scientific inquiry processes. Crawford concluded that teachers' involvement in high school students' inquiry-learning environments was most important through various types of role-playing, which provided students with opportunities to communicate with teachers and experts outside the classroom for help in carrying out an inquiry investigation. The next study, by Keys and Kennedy (1999), also emphasized the teacher's role in creating inquiry environments so that students can understand the nature of scientific inquiry.

Keys and Kennedy (1999) developed the case history of one teacher, Ms. Kennedy, during her teaching of science units about light and weather for one academic year, describing how she provided students with opportunities to understand the nature of scientific inquiry. Their study used 28 class observations, field notes from nine interviews with the teacher and students, and transcriptions of three formal interviews with the teacher. The teacher's four major instructional processes related to teaching science inquiry were reported. First, students had opportunities to explore their own questions. Ms. Kennedy paused in her instruction to investigate students' questions that arose in the classroom context to plan inquiry lessons around ongoing activities. Second, students were encouraged to use independent procedural and social skills. Instead of introducing inquiry processes step by step, Ms. Kennedy challenged students to use their reading and thinking skills to interpret directions, to transfer their understanding to the hands-on materials, and to modify any procedures in their groups. Third, students used data inductively to build explanations and concepts. Ms. Kennedy used students' observations and interpretations as primary sources to build their conceptual understanding, by making students present their data or identify the patterns from the data for generalizations.

Keys concluded that Ms. Kennedy created opportunities for students to express their opinions freely by developing their research questions to carry out experiments and develop scientific explanations inductively. Ms. Kennedy allowed time for students to discuss how applying their knowledge to new situations could deductively support their findings through hands-on activities. The next study, by Maor and Taylor (1995), also described how students could have been given opportunities for learning science as inquiry with the help of teacher who used constructivist epistemology in the context of computer technology investigation.

Maor and Taylor (1995) investigated the mediating role of teachers' epistemologies in high school computer classes in which students engaged in scientific inquiry and developed scientific understanding of a natural phenomenon through a computer database developed by scientists. Two classrooms, one with a teacher with transmissionist epistemology and the other with constructivist epistemology, were compared in how they provided opportunities for students to develop higher-level thinking skills.

Maor and Taylor (1995) reported that the teacher with constructivist pedagogy—regardless of the computer learning context—designed an inquiry learning environment that facilitated students' scientific inquiry and use of higher-level thinking skills, by sharing ideas with students and by encouraging students to generate creative questions for their complex investigations. Whenever students seemed to have a problem to discuss, the teacher, Sam, initiated an interactive form of whole-class discussions that encouraged students to interact with each other and to offer alternative ideas. Sam involved students in complex arguments with conflicting ideas that were needed for students to understand how their collected data or information supported their hypotheses. Students were exposed to conflict situations and were able to elaborate on their ideas through negotiations with each other. Therefore, students in Sam's class were found to become more comfortable with whole-class discussion, which became a routine and integral part of their learning process.

These studies (Crawford, 2000; Keys & Kennedy, 1999; Maor & Taylor, 1995) describe how teachers implemented scientific inquiry activities successfully to provide students with opportunities to understand how scientists do their investigation. Teachers in these studies provided opportunities for students to frame their own questions that were connected to the real world, to design procedures to investigate a phenomenon by sharing ideas with peers and teachers to see if their procedures were testable or if they chose appropriate variables, to collect data with enough sources, and to conclude the results based on collected data that was connected to the original research questions. These processes implemented by the teachers' role of scaffolding required that students should communicate with peers or teachers in groups or with the whole class in order to develop the skills of inquiry process and reasoning, that help students understand how scientists construct their knowledge. Therefore, teachers' scaffolding that provides opportunities to develop ideas or arguments with peers is considered a potential component of scientific inquiry in the classroom.

In addition to the teachers' role of scaffolding, Toth, Suthers, and Lesgold (2002) and White and Frederiksen (1998) developed two new models as aids for scientific inquiry in which students could have opportunities to reflect on the procedural and reasoning skills involved in scientific inquiry. The first component, *external representations to scientific practices*, refers to both the cognitive and social components of inquiry as the pedagogical tools needed to teach fundamental inquiry process skills. In Toth, Suthers, and Lesgold (2002), students used software-based mapping processes with different shapes indicating the relationships between evidence, data, hypothesis, and explanation. Students could understand how their data did or did not support their hypotheses and how their conclusions reflected on their data in answering the questions. In White and Frederiksen (1998), students used inquiry models of computer-based curriculum designed by the authors in this study. The second component, *explicit reflective assessment rubrics*, supports students' interactions with external representations during problem-solving activities to see how they met the goal of scientific inquiry. This explicit reflective assessment allowed students to combine whole procedures of scientific inquiry and to think about how their questions were framed, what variables were adapted, how the data were collected, how hypotheses were supported or refuted by data, how new hypotheses were developed from other experimentation, and so on, through communication with peers in groups or teachers in a whole class setting.

Summary: Scientific Inquiry

Some implications of scientific inquiry teaching and learning in the classroom can be seen based on the studies reviewed above. First, teachers can use instruction to encourage student thinking about inquiry tasks; one way to do this is to base instruction on a constructivist view of learning. A teacher's role of scaffolding that is rooted in a constructivist epistemology provides potential for students to develop reasoning skills from their inquiry experiences. Second, explicit reflective assessments designed by researchers or teachers aided students' reasoning processes during inquiry investigation. Third, teachers need to provide students with opportunities for argumentation and explanation as well as exploration and experimentation. The problems with school scientific inquiry result from the emphasis on hands-on activities only without minds-on activities. Students need to understand how scientific knowledge is constructed by sharing and arguing their ideas with their peers and teachers based on their experimentation and observations. All of the teachers who were considered to be successful in implementing scientific inquiry in the classroom provided many chances for students to argue about how they developed their questions from the real world, how they collected their data, how their data supported or rejected hypotheses, and how their conclusions reflected on the data.

At this time, teachers hold the potential to make scientific inquiry successful by prompting, giving hints or clues, or questioning to scaffold students' progress in understanding the nature of scientific inquiry. Students cannot understand the purpose of scientific inquiry only through developing procedural skills from experimentation. Students can understand the purpose of scientific inquiry through developing scientific reasoning skills from argumentation as well as through developing procedural skills from experimentation. Then, what is scientific argumentation? What are students supposed to do during argumentation to understand scientific inquiry? The next section of this review will examine the definition and use of scientific argumentation in scientific inquiry.

Scientific Argumentation

Educational literature uses the term argumentation in two different ways (Driver, Newton, & Osborne, 2000). An argument is defined as advancing a reason for or against a proposition or course of action, which means telling others and persuading them about the strength of the case being put. For example, teachers provide a scientific explanation to a class or to a group of students with the intention of helping them understand it as reasonable. Another meaning of argument is needed when students are developing the skills of scientific argument for themselves rather than providing an audience for the teacher's reasoning. Students need to practice such scientific reasoning for themselves: articulating reasoning to support or refute a particular scientific claim, persuading or convincing peers with supportive evidence, and expressing or relating alternative ideas to others. In this paper, the second definition of argument, one which students can construct during their practice using reasoning skills with alternative ideas to reach acceptable claims, will be used. The next section will review in what ways scientific argumentation could have limitations in the context of scientific inquiry and how scientific argumentation could take place successfully to meet the purpose of scientific inquiry in the classroom.

Scientific Argumentation in the Classroom

How well do science teachers understand the purpose of scientific argumentation in their teaching? How often do they use this teaching strategy to develop students' reasoning skills? The next study revealed the limitation of using scientific argumentation in general science teaching at the secondary level in England.

The study by Newton, Driver, & Osborne (1999) was to determine whether secondary science teachers in England provide students with opportunities to develop and rehearse skills of argumentation during the lesson. The authors designed an observation schedule to see how much time science teachers from seven schools assign for argumentation during thirty-four science lessons from grades seven to eleven.

The findings revealed that science lessons were teacher-dominated, with a heavy emphasis on teacher exposition and recitation forms of question and answer interaction. Dominant practices in secondary school science lessons did not include activities that supported discussion, argumentation, and the social construction of knowledge. Students had few opportunities to express alternative ideas that could be necessary to understand how scientific knowledge is constructed. The 14 experienced science teachers were interviewed to answer questions about this lack of opportunity for students to share, negotiate, persuade, or explain their knowledge. Those teachers had difficulty with the pedagogical task of managing discussion effectively with the ineffective materials that were used in the classroom. Teachers did not have the confidence or perspective to come up with necessary pedagogical skills to develop students' discourse or argumentation, even though they valued argumentation for students' learning.

Newton, Driver, & Osborne (1999) illustrated the problem of how seldom teachers provide opportunities for students to use argumentation to reflect on and generalize knowledge and to develop reasoning skills. The main barrier to students' argumentation was the lack of teachers' pedagogical skills, leading to the conclusion that appropriate resource materials should be available to help scaffold teachers' initial attempts at adopting new models or functions, such as those using argumentation. In general, science teachers were found not to have well-developed perspectives or pedagogical skills needed to provide students with opportunities for scientific argumentation in which they can understand how scientific knowledge is constructed through social interaction with peers or teachers.

Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) stated that argumentation is particularly relevant in science education since a goal of scientific inquiry is the generation and justification of knowledge claims, beliefs, and actions. To better understand how to promote students' argumentation that supports their doing science in the classroom, Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) examined student argumentation in a natural setting at the high school level, during six one-hour sessions over two weeks. The teacher's instruction included sessions to introduce basic genetic concepts, small group work on worksheets, students' qualitative problem-solving and discussion with the whole class, lectures about biological change and evolution, and small group discussion on handouts with hypotheses about chicken problems. To solve the problems, students were asked to provide possible causes with supporting and refuting reasons.

For data analysis, audiotapes were transcribed in three dimensions. First, the authors identified each unit to see if students were "doing the lesson" or "doing science" to differentiate school culture as procedural display from science culture. Second, there was argumentative analysis, using Toulmin's (1958) argument pattern with its components of data, claim, warrants, backing, qualifiers, and rebuttals. Third, for the epistemic analysis, a set of epistemic operations was constructed in terms of induction, deduction, causality, definition, classification, appeals, consistency, and plausibility. Results in this study were reported based on these three dimensions.

In the first dimension, there were instances of *doing science*, such as talking about alternative ideas and reaching consensus through argumentation, and also *doing the lesson* as procedural, such as talking about what to write or discussing a problem with only one hypothesis. The authors found that a substantial part of the exchanges between students could belong to the school culture as procedural display, which counted as *doing the lesson*, but were not related to the stated goals for learning. On the other hand, there were instances that appealed not to school culture but to science culture.

In the second dimension, an argumentative operation using Toulmin's (1958) approach, there were usually claims and warrants but few qualifiers, backing, or rebuttals in small group and whole class argumentation. Most of the time, claims were offered without any relation to other components in students' argumentation. For example, in one group's discussion about chicken heredity, the authors coded 99 elements as part of an argument. From these, 66 were claims, 21 warrants, 10 data, and 6 backing. In the small group discussion, there were no qualifiers or rebuttals. In the whole group, claims were also the element most frequently used. Most of the time, the claims were offered without any relation to other elements in the argument.

Finally, in the third dimension, epistemic operations, students' argumentation mainly included *causality*. *Analogies* were also used in the discussion, such as relating natural color to natural food, the change in color to cosmetics, or yellow color of chickens to yellow feed. The lack of *consistency*, however, was stated as an obstacle to attaining the goals related to the transfer of knowledge and to the application of knowledge to different instances and situations.

Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) concluded that the teaching strategy used for students' argumentation limited the opportunity to use and develop reasoning skills in constructing new knowledge, such as connecting evidence to explanation or finding coherence between explanations and prior knowledge. The teacher could create a climate of argumentation by encouraging students to express and define their opinions collaboratively. Students asked one another to explain or support their claims with some warrants and backing to support their positions in spite of the few opportunities to use argumentation in the classroom. This study implied that a teacher's effort to encourage students to express and defend their ideas in groups with their own knowledge could make it possible to create an inquiry environment with opportunities for scientific argumentation.

The two aforementioned studies, by Newton, Driver, and Osborne (1999) and Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000), illustrated how students had few opportunities for argumentation in general science learning or in scientific inquiry contexts in the classroom. However, the authors in these two studies implied that scientific argumentation is essential to fruitful scientific inquiry. It is important that teachers strive to provide students with opportunities for argumentation and for using reasoning skills as well as procedural skills for investigation.

The Development of Scientific Argumentation in the Classroom

While some limitations and problems exist in using scientific argumentation in the classroom, some researchers concluded that students could have opportunities to develop scientific argumentation, through which students understand how scientific knowledge is constructed based on collected evidence or data. The next study, by Vellom and Anderson (1999), showed how teachers created scientific argumentation opportunities for students in the context of scientific inquiry in the classroom by getting over the limitations of scientific argumentation that are found in the classroom.

Vellom and Anderson (1999) examined the authentic discourse between sixth-grade students and one teacher to illustrate the nature of student arguments, students' learning as they negotiated content and issues, and interactions within their collaborative groups. Data were collected over ten weeks through videotapes, field notes, and all students' products of all whole-class sessions as well as the work of two target groups of four students, using the content of mass, volume, and density. All students took pre- and post-instruction conceptual tests; however, only two target groups of four students participated in pre- and post-instructional interviews about conceptual understanding, understanding of the nature of science, and group dynamics. One professor, who had been working with the teachers for two years to create working curricular units and teaching strategies to engage students in science problems and phenomena, taught this unit with the aim of exploring self-regulated learning in a collaborative group setting at an urban middle school science classroom.

Vellom and Anderson (1999) described what kinds of instructional strategies were employed to create opportunities for students to discuss the scientific community, during which they could develop certain explanations, share alternative ideas, and support or refute their own and others' ideas with evidence. The students' job was to make possible stacks of three different density solutions using vials, droppers, and cards containing prompting questions that guided students to explain, describe, and find patterns.

The results were as follows. First, students understood the content of density through experimentation and argumentation with peers and the teacher through a whole class discussion or working in groups. At this time, students could get conflicting claims from the other students, and they constructed their arguments with their own evidence from their experience or designed experiments based on the teacher's systematic questions. Second, students could develop the ability to differentiate evidence from data while they were persuading their peers which stacks were possible or not using rhetorical strategies. Students' attempts to reach consensus led to their increased reliance on scientific persuasive strategies. Here, students began to act as a community of validators in developing explanations. Third, students learned that they had the power to discover the truth without being told, but this did not lead them to learn more deeply about the nature of scientific knowledge. In other words, students did not understand that constructing scientific knowledge is a creative process, but at least they believed that they were experiencing a new way to discover facts. Fourth, students lacked the shared standards and conventions to display and compare results, discuss differences in ways that would ensure everyone a chance to be heard, and decide when and how differences in claims could be adequately resolved.

Vellom and Anderson (1999) described how the intervention of lesson sequences employed in this study developed more opportunities for argumentation among students with the help of one professor, who taught the unit of density and facilitated students' fruitful discourse. This lesson sequence consisted of three sessions: (a) a teacher-led demo to gain students' interest or motivation with their own evidence from their experience, (b) the teacher's interaction with student members of each group to help them develop their poster for presentation by collecting data and sharing their ideas with one another, and (c) group presentations to develop argumentation for or against another group's findings. During this process, students could understand the nature of scientific argumentation as well as scientific inquiry.

Summary: Scientific Argumentation

Argumentation is defined as a way to construct acceptable claims by reasoning through alternative ideas on a certain issue (Driver, Newton, & Osborne, 2000). Based on this definition, scientific argumentation is the way that students discover their own findings through the process of accepting or critiquing other students' alternative opinions, using evidence or data collected from their experimentation. This is the purpose of scientific inquiry.

However, the findings of these two studies, Newton, Driver, and Osborne (1999) and Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000), showed that there is now little opportunity for scientific argumentation that is so essential to meeting the goal of scientific inquiry. They observed few opportunities for argumentation in science teaching in general. Furthermore, if there were any opportunities for argumentation, that argumentation was not developed enough to require students' reasoning skills of dealing with claims using evidence through rebuttals or warrants. Students' argumentation was found to be more effective in developing procedural skills than reasoning skills. However, to develop students' argumentation through which they can really understand the nature of scientific knowledge, the teachers' role of facilitating argumentation is vital.

The curriculum designed by the teacher in the study by Vellom and Anderson (1999) provided more opportunities for students to develop argumentation. Students had chances to explain their findings with evidence collected through the experimentation. Students also had the ability to critique others' claims with refuting evidence. At this time, the teacher used clues or hints that facilitated more argumentation among students' groups.

The reviewed studies of scientific argumentation suggest the possibility of developing argumentation among students with the help of teachers. Scientific argumentation cannot exist individually; instead students agree or disagree with others' alternative opinions using their own evidence as acceptable scientific knowledge. Students need to have opportunities to explore their own arguments on different positions with reliable evidence from the experiment, thus developing the confidence and skills to argue effectively. How can students develop scientific procedural and reasoning skills through scientific argumentation? The next section will illustrate how the social practices of group work provide more chances for scientific argumentation. The students' roles in groups are also influential in developing more fruitful opportunities for scientific argumentation.

Scientific Argumentation as a Social Practice

Students develop their reasoning skills by making their opinions more acceptable, by supporting their own theories or refuting others'. For this process, students need to have chances to talk freely about their own ideas with their peers and teachers in the classroom. The process of scientific argumentation will be shaped and validated by peers and teachers with whom students work (Richmond & Striley, 1996). The next studies showed how students develop scientific argumentation skills in groups as a social practice. Alexopoulou and Driver (1996) stated that groups of four students had more opportunities to develop their scientific argumentation skills than did pairs of two students.

Alexopoulou and Driver (1996) compared pairs and small groups of four students at the secondary level in Greece to investigate the nature of the processes by which students negotiate, discuss, and explain their ideas about simple physical phenomena, and to see what the relationship is between group discussion and the development of individual students' physics reasoning. Their hypothesis was that the number of group members would influence the ways students negotiate their ideas.

Alexopoulou and Driver (1996) selected 86 students, ages 14 to 15, at four different schools. Students took pre- and post-tests that included six open qualitative reasoning questions in the content areas of conductivity, change of state, and free fall, subjects that they were familiar with. For example, one question about conductivity asked which of two spoons, a metal and a wooden one, which are in a jug of hot water, would be more comfortable to the touch, and why it would be. After completing the individual pretests, students discussed all six questions in self-selected, single-sex groups of either two or four students. Each group was asked to write down an agreed-upon response and the supporting reason. If they were unable to agree, they provided their different responses as well as their reasoning. Group discussions lasted sixty minutes and were audio-taped, and post-tests occurred with the same questions two to three weeks later.

There were two kinds of analysis of the data. The first analysis was about students' changes in reasoning from the pre-test to the post-test. The tests were analyzed to be progressive, regressive, or not changed by three scores (-1, 0, +1) in reasoning for each student. Students in groups of four progressed slightly more (17.4%) than the pairs (16.7%) and regressed considerably less (8.3%) than the pairs (14.9%). Students' gain scores in groups of four were higher than those in pairs in all four classes that participated in the study.

The second analysis was about group discussion. All discussions were transcribed and 16 samples were selected for an in-depth analysis of discourse, which included four progressive and four regressive discussions in both pairs and groups of four. Three dimensions of codes were used to classify the discourses. The first dimension, an explicit one, was to see how students construct their own arguments, such as predicting, justifying, providing evidence, evaluating, applying, and changing opinions. The second dimension, another explicit one, was to see how the students interact with one another socially, such as agreeing, disagreeing, and asking questions. The third dimension, an implicit one, was to see how students react to others, being supportive or aggressive or showing uncertainty or confusion. The frequencies and patterns of different types of codes for the 16 selected progressive and regressive discussions were compared for pairs and groups of four.

The two results, students' reasoning and group discussion, were compared between pairs and groups of four irrespective of the gender of the participants. First, the peers' discussion in pairs depended a lot on participants' individual dispositions and goals. When students' perceptions of their abilities in pairs were compared to those of the others in groups of four, their competitive or collaborative attitudes toward each other influenced group discussion processes and peers' subsequent learning. Conflicting opinions helped group discussion only when they were each willing to openly acknowledge their differences and explore ideas. One student's openness about his lack of understanding and his willingness to confront the implication of the social conflict with another group member helped him to develop his physics reasoning. Another example from the regressive discussion of a pair illustrated how the covering up of unclear points as well as the emergence of competitive attitudes prevented them from developing their ideas. Even though there were differences in terms of physical reasoning, two students were unwilling to openly recognize their disagreement. The students, instead, tried to avoid argumentation and one of them suggested that they should go to the next question in an effort to cover his lack of understanding of the other's assertion.

Second, the process of negotiation of meaning in groups of four depended more on the interrelation of group members' efforts to avoid the raising of objections causing conflict, rather than individual's perceptions and interpretation of the situation, which was the case with pairs. However, findings also showed that the students' efforts to avoid conflict and to resolve disputes—through unconvinced agreement, majority voting, or quick decisions to write down the competing views—caused a lack of students' progress in physics reasoning. Students' conflicts helped only when students were exploring alternatives openly without turning their disagreement into interpersonal conflict. One example from a progressive discussion of a group of four boys illustrated how interpersonal tension caused by their varying ideas was resolved through the social support of a peer and led them to progress in physics reasoning. When one of the students raised his objection, there was a discussion of the different view rather than of the winning view, which helped him to clarify his ideas. Another example from the regressive discussion of four boys illustrated how the peers failed to clarify their meanings by turning their differences in physics reasoning into interpersonal conflicts.

Alexopoulou and Driver (1996) concluded that peers' modes of interactions on the social level through group argumentation was more limited in pairs than in groups of four, and pairs had more difficulty in negotiating their views and dealing with disagreement. Pairs found it more difficult to overcome the notion of right or wrong responses to explore meaning, whereas groups of four found disagreement to be more easily diffused through social interaction. However, different views in groups of four diverted attention from the search for the right answer toward a negotiation of meanings. A willingness to be open about their thinking process and to raise disagreements about physics reasoning was most important; it is implied that this classroom atmosphere could be supported by teachers.

Alexopoulou and Driver (1996) pointed out how different types of groups influenced students' abilities to use argumentation to develop their physics reasoning. In groups of four, students gained more alternative ideas from conflict and tended to develop meaning through negotiation rather than searching for the right answer the way the pairs did. Group setting played a role in providing students opportunities for more argumentation in negotiating alternative ideas. Some findings in this study implied that students' roles facilitated argumentation. That is, students were reported to find it easier to enter arguments and to discuss their conflicting perspectives through role-playing. Role-playing is then suggested to be a factor in facilitating and regulating peer interaction, providing a social plan for discussions with a different balance of power. The next study, by Herrenkohl et al. (1999), illustrated how students' roles in groups promoted their degrees of argumentation in the context of scientific inquiry.

Herrenkohl et al. (1999) reported the importance of using small groups with specified roles for students. *Procedural roles* monitor each member's record of the experiment, maintain group materials, read the problem card, or keep time. *Audience roles* predict and theorize, summarize results, and relate predictions and theories. This study indicated that students' roles were crucial in guiding and focusing on a set of issues at a time. Herrenkohl et al. (1999) found that students' argumentation was fruitful when using explicit instructions with a set of social roles that motivated collaboration and argumentation with peers in small groups.

Students' arguments were also enhanced by the teacher-designed public documentation that helped students modify their thinking with more evidence. In those classes, it was found out that students' argumentation became more elaborate and productive based on explicit instructions. Overall, it is necessary to make scientific thinking strategies and socio-cognitive roles explicit to students so that they can engage in significant cognitive work together. Besides specified group roles, the type of leader in students' groups is another component that facilitated students' argumentation. Richmond and Striley (1996) examined how the different leader type in students' groups, as well as students' different roles, influenced student argumentation.

There were three different leader types involved in students' argumentation. First, *inclusive leaders* bring up an idea and ask group members for their reactions or opinions and then carefully consider their peers' input. For example, the leader in a group asked the rest of the members to participate in argumentation by asking questions and encouraging comments. Students in this group worked collaboratively and closely in sharing their ideas. Second, *persuasive leaders* present their ideas to the group and, if challenged, attempt to convert others by elaborating on their reasoning or by explaining the validity of their point of view. If a challenge were repeated, the leader would sometimes refuse to negotiate. For example, the leader in a group attempted to have the rest of the members agree with his idea or to regard his own idea as the most satisfactory. Third, *alienating leaders* possess strong beliefs, declare their point of view, disregard the input of others, and effectively alienate themselves from the discussion process.

Richmond and Striley (1996) concluded that knowledge through argumentation was considered with both *inclusive* and *persuasive* leader types, but not with *alienating* leaders. Furthermore, the authors expected that social and intellectual achievement would be greatest for those students in groups with inclusive leadership, since groups with inclusive leaders were found to engage students in more discussion. The findings of this study implied that educators should develop the capacity for inclusive leadership and equitable participation in the classroom.

Summary: Scientific Argumentation as a Social Practice

Students need to have opportunities to share or critique others' ideas with their own evidence from their experience or experimentation. This is how students can gain understanding of the nature of scientific knowledge, which is the goal of scientific inquiry. For this goal, it is essential for students to be grouped so as to have social interactions with peers or teachers (Alexopoulou & Driver, 1996). Alexopoulou and Driver (1996) found that groups of four students were more successful in developing meaningful scientific reasoning through negotiation, gaining more alternative ideas from conflict rather than just searching for the right answer in pairs. Regarding students' roles in groups, Herrenkohl et al. (1999) reported that specified procedural and audience roles were crucial in guiding students and helping them focus on argumentation. In addition to this, Richmond and Striley (1996) illustrated that the type of leader in students' groups influenced the students' engagement in argumentation. The *inclusive leader* in students' groups allowed others more chances to use argumentation by asking questions and encouraging comments than the *persuasive leader*, who seemed to dominate the argument and place little value on others' alternative ideas, or the *alienating leader*, who seemed to disregard the others' opinions altogether.

These findings in the above studies support assertions that science is understood as a social practice through students' argumentation (Driver, Newton, & Osborne, 2000). It is important that students appreciate the basis for scientific knowledge or claims. It is only through students' opportunities for argumentation between competing theories or different interpretations of natural phenomena or events that students can evaluate how a decision between those completing claims is made. This is what students are expected to do during their scientific inquiry in the classroom. We expect students to develop their scientific reasoning skills through argumentation as well as scientific procedural skills through experimentation. Then, what kind of scientific reasoning is needed for students to understand the nature of scientific knowledge? The following researchers describe what scientific thinking is and how students demonstrate it during scientific inquiry.

Scientific Thinking

Students are expected to develop their scientific thinking through scientific argumentation in the classroom. Then, what is scientific thinking? What kind of scientific thinking skills are developed through students' argumentation? Kuhn (1989a) defined scientific inquiry as the coordination of theories and evidence. Kuhn in this article argued that scientists reconcile their ideas with the former competing ideas with more evidences and justify them to the community. In this process, a scientist is able to articulate a theory that he or she accepts, to know what evidence could support or contradict it, and to justify why the coordination of theory and evidence leads him or her to accept that theory or reject others that explain the same phenomenon.

Scientific thinking is also defined as the process of decision-making in choosing between different explanations and reasoning what criteria lead to that choice (Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000). For this purpose, the authors added that decision-making through argumentation requires an adequate content domain and context of classroom, which influence students' abilities of thinking as knowledge-producers rather than knowledge-consumers. Kuhn (1986) also argued that students could develop scientific thinking abilities by practicing them, such as adjusting evidence to fit a theory or adjusting a theory to fit the evidence, or coordinating the two to evaluate their hypotheses. Then, how can teachers create this inquiry environment for students to develop their scientific thinking skills? Knowing the difference in thinking skills between students and scientists could help educators and teachers to design curricula or teaching strategies that facilitate students' practice of the scientific thinking process. The next section will review how students think differently from scientists.

Scientific Thinking of Science Students and Scientists

Reif and Larkin (1991) argued that students' difficulties in science learning resulted from their unfamiliarity with the knowledge domain of science, whereas experienced scientists cope successfully with the goals and cognitive domain of scientific knowledge. The authors analyzed and compared the domain goals and cognition of everyday versus scientific knowledge to show what kinds of learning difficulties were caused by students' unfamiliarity with the nature of scientific knowledge. The main goal of science is to achieve optimal prediction and explanation by devising special theoretical knowledge that permits inferences about observable phenomena, whereas the main goal of everyday life is to lead a satisfying life and to cope satisfactorily with one's environment. With these main goals in mind, students view scientific knowledge as a collection of facts and formulas rather than a conceptual structure enabling numerous predictions. Students tend uncritically to accept commonsense notions and knowledge acquired from authoritative sources, such as teachers or textbooks. Based on these students' learning, the role of school science is to reward memorization of factual knowledge rather than the flexible use of such knowledge.

Reif and Larkin (1991) also noted the difference in *methodology* used in solving problems between everyday and science domains. The need to solve problems requires one to make decisions, choosing among the many possible actions leading to the desired goals. Everyday problems can be solved by depending on a large amount of accumulated knowledge to make short inferences in a particular local context; whereas scientists invented formal problem-solving methods designed to implement long inference chains with great precision, such as with mathematical and structural formulas. However, this formal method is not sufficient for all scientists' tasks. Scientists need to plan problem solutions, formulate sub-problems, and design experiments suggesting possible mechanisms for observed effects.

However, students at schools commonly import into science problem-solving strategies used in everyday life, where inference chains are shorter due to a greater reliance on accumulated context-specific knowledge. Often students perceive no need for formal methods or find such methods difficult to implement, instead using informal methods from everyday life. Teachers often teach students by presenting some pertinent scientific concepts and principles, showing examples of typical problems but not giving students practice in solving problems.

Driver, Asoko, Leach, Mortimer, and Scott (1994) differentiated the "commonsense" knowledge held by students from scientific knowledge held by scientists in explaining a natural phenomenon. Commonsense knowledge is valid within everyday discourse and scientific knowledge is valid in the scientific community. In addition, commonsense reasoning, through it is complex, exists without explicit rules, whereas scientific reasoning is characterized by the explicit formulation of theories that are communicated and evaluated in the light of evidence.

Dunbar and Klahr (1989) and Kuhn (1989a) investigated students' scientific thinking skills to see how they think scientifically in the context of experimentation. First, Dunbar and Klahr (1989) investigated how scientists and students react differently in a simulated scientific discovery context. To do a task, subjects had to formulate hypotheses based on their prior knowledge, conduct an experiment, and evaluate the results of their experiments. Second, Kuhn (1989a) stated that the metaphor of children as scientists is acceptable in terms of scientific understanding, but not in terms of the process of scientific thinking. Kuhn (1989b) indicated that the process of scientific thinking differs significantly between children and scientists. These two research papers investigated how children's scientific thinking skills are different from those of scientists.

Klahr and Dunbar (1988) selected twenty undergraduates who had prior experience in computer programming. After becoming familiar with the BigTrak robot keypad designed by researchers, all of the undergraduates were asked to find the function of RPT (repeat) key by developing their own hypotheses. The participants were certain how the RPT key worked within an average of 45 minutes, and all their behaviors were videotaped. Nineteen out of twenty subjects discovered how the RPT key worked within 45 minutes. There were two types of strategies in which these subjects evaluated their hypotheses and constructed new ones if their prior ones conflicted with their evidence from experimentation. One strategy was *hypothesis space*, in which subjects evaluated their initial hypotheses in a certain frame and searched a new frame using different hypotheses when they did not find evidence supporting their original hypotheses. The other strategy was *experimental space*, where subjects did experiments by running programs to find the function of RPT to see how their hypotheses worked out.

Based on these two strategies, Klahr and Dunbar (1988) concluded that all subjects could be divided into two groups. One subject type was *theorist: theorists* started with the wrong frame of hypotheses but used the two different strategies, *hypothesis space and experimental space*, to switch frames from the wrong one to the right one. Seven out of twenty subjects were *theorists*, and were seen to construct new hypotheses, conduct experiments, and evaluate them. If subjects had gathered enough evidence to reject their initial hypotheses, they switched their frames from one to the other and accumulated more enough evidences to reject the initial hypotheses to propose new ones. The other subject type was the *experimenter*, who just stated their hypotheses and then conducted experiments to evaluate them. Subjects who were classified as *experimenters* just conducted experiments without an explicit statement of new hypotheses, even though they realized that their initial hypotheses were inadequate. Klahr and Dunbar (1988) found that the big difference between *theorists* and *experimenters* was that *experimenters* conducted more experiments than *theorists* but these extra experiments were conducted without explicit hypothesis statements.

Dunbar and Klahr (1989) also did the same study with 22 children ranging from third to sixth grade, with the same goal of investigating scientific thinking process of adults. All of the children had enough time to become familiar with the BigTrak robot keypad and then were asked to find the function of the RPT key. Only two of the 22 children discovered the correct rules. Even though the children observed many experimental programs inconsistent with their initial hypotheses, none of them were able to induce new hypotheses from their prior experimentations.

Dunbar and Klahr (1989) suggested two things based on these results. First, children did not have sufficient knowledge to generate another frame by searching *hypothesis space*. In this case, children did not generate the role of N with the RPT key from the role of counter to the role of selector. Second, children did not search *experiment space* to induce a new frame; instead, they tried to find new evidence that could support their current frame. As a result, children generated a number of hypotheses within the current frame, the N-role of counter that was not observed by adults in the first study. This indicated that the *hypothesis space* visited by the children was very limited, even though they explored the *experiment* and *hypothesis spaces* for some time.

Three main differences between adults and children existed in terms of scientific thinking skills. First, children proposed hypotheses that were different from adults. The criteria the children used for accepting hypotheses were different from those used by adults as scientists. Children often conducted a single experiment to say that they discovered how the device worked. However, adults as scientists conducted a number of experiments before they were convinced that their hypotheses were correct. Second, the children did not give up their current frame to search the *hypothesis space* for a new frame or use the results of an *experiment space* search to generate a new frame. Children just generated new hypotheses in their current frame rather than search a new frame by visiting *hypothesis space*. Third, children did not try to check whether their hypotheses were consistent with their data. The children just tried to find evidence that could support their current frame rather than find a new one based on their evidence that conflicted with their current hypotheses. When an experiment produced disconfirming evidence, children just conducted some new experiments that might confirm their current hypotheses. Children tended to ignore evidence that conflicted with the current hypotheses.

Consequently, the adults as scientists had a 95% success rate, whereas 90% of the children failed to discover the function of the BigTrak device. Dunbar and Klahr (1989) concluded that these differences did not lie in the ability to generate informative experiments, since there were few differences in the regions of the *experiment space* visited by the children and the adults, but instead lay in their reasoning and inducing skills that connected their current data from experiments with their hypotheses. Another possible reason for these differences was in the knowledge about how to evaluate hypotheses. Children appeared to lack the knowledge that results of earlier experiments must be considered when evaluating a hypothesis.

Kuhn (1989a) also argued that children do not have the meta-cognitive skills available to properly evaluate evidence. Kuhn (1989a) discussed two kinds of scientific thinking skills that were necessary to understand the nature of scientific knowledge by comparing those skills between children and adults or scientists.

First, children could not differentiate theory from evidence. One student, a sixth grader, was asked to evaluate graphically presented evidence in eight instances, with covariation and non-covariation of various foods that children ate at school with their susceptibility to colds. When the student was asked to evaluate the first instance of what would be covariation evidence, he made a theory-based response about the cake variable, which he believed was implicated in catching cold. However, that student was found to not be able to clearly differentiate theory from evidence during interviews with the author. He appeared especially unable to clearly distinguish between theory and evidence when they were compatible. Since both evidence and theory connected to the conclusion, they appeared to be the same in justifying the conclusion. This was the way that children appeared not to differentiate the different sources of support for their beliefs. Kuhn stated that this vacillation between theory and evidence as the basis for justifying judgments was common among sixth graders, declined by adulthood, and was never found among experts as scientists.

Second, children could not adjust evidence to fit theories or vice versa. Kuhn studied how children used evidence to support their theories in one of her studies. Evidence was portrayed by actual balls placed in baskets labeled *Good Serve* and *Bad Serve,* and the subjects were asked to relate the evidence with two different theories. One student in the third grade was asked to evaluate these two theories; he theorized that size was causal (big for *Good* and small for *Bad*) and color was non-causal. That student predicted that *Mr. Size* would win and *Mr. Color* would lose, but he was confused in using evidence that would support or conflict with his theory. Even though the student found that his responses to the interviewer were conflicting with the theory, he could not notice what the problem was generated to give up his theory with insufficient evidence. This demonstrates one type of students' scientific thinking: adjusting evidence to fit a theory in order to maintain alignment between theory and evidence. The other type of scientific thinking was adjusting theory to reduce its inconsistency with evidence. For example, one of the students failed to generate evidence that demonstrated correctness of the opposing theory. This illustrates the issue of how to coordinate theory and evidence after differentiating them.

Kuhn (1989a) compared her study with that of Klahr and Dunbar (1988) by using a *developmental continuum.* At one end of this *developmental continuum*, students cannot differentiate theory from evidence well enough to construct the relationship between the two. In Klahr and Dunbar's (1988) terms, *hypothesis space* and *experiment space* exist as a single entity without differentiation. In their study, children did not visit these two spaces separately to construct new hypotheses in a new frame by visiting *hypothesis space* even though they found evidence conflicting with their current hypotheses. At the other end of this *developmental continuum* is the full differentiation and coordination of theory and evidence, which is needed to construct the relationship between these two. In Klahr and Dunbar's (1988) study, adults as non-graduate students could visit these two spaces separately to generate a new frame where they could construct new hypotheses based on their evidence, whether supporting or conflicting with the current hypotheses, from their experimentations.

These two studies, Klahr and Dunbar (1988) and Kuhn (1989a), illustrated what scientific thinking is that students need to develop during their scientific inquiry learning. Students need to develop the skills of differentiating and coordinating theories and evidence when they evaluate their hypotheses to construct their scientific arguments, which are necessary skills to understanding the nature of scientific knowledge. However, through this research, students were found to be not as qualified to use those skills when compared to scientists. Chinn and Brewer (1993), however, discovered different findings by investigating how scientists and students respond to anomalous data, which is essential to understanding knowledge acquisition in science classrooms. The authors stated that a theory could be changed by taking into account three different decisions an individual made in order to coordinate new anomalous data with existing data. First, the individual must decide whether the new data are as believable as the valid data. Second, the individual must decide if and how the acceptability of the data can be explained. Third, the individual must determine if and how the theory needs to be changed in order to achieve a successful coordination of theory and data. Chinn and Brewer (1993) found similarities in the responses of scientists, nonscientist adults, and science students; whereas Kuhn (1989) and Dunbar and Klahr (1989) found that the metaphor between scientists and children was not supported by their scientific thinking skills.

Summary: Scientific Thinking

Four different studies, Reif and Larkin (1991), Dunbar and Klahr (1989), Kuhn (1989), and Chinn and Brewer (1993), revealed that children or science students did not show the same abilities of scientific reasoning skills that scientists displayed when they evaluated their hypotheses. Basically, Reif and Larkin (1991) reported that scientists correctly perceived the goals of scientific inquiry, employed methodology to investigate a natural phenomenon, and devised ways of thinking to develop explanations using their data based on the scientific domain. Children or science students in the classroom did the same things, only based on their everyday domain. Students did not have the abilities to differentiate theory from evidence, and they tended to consider both theory and evidence as a single entity. Students continued to develop other hypotheses in the same frame, the role of N-counter, in spite of conflicting evidence, rather than searching for new hypotheses in a new frame.

For the purpose of developing students' scientific thinking skills, it is suggested that teachers should provide chances for students to practice dealing with theory and evidence. The empirical evidence regarding discovery suggested that students would fail to discover the alternative theories without sufficient guidance or hints from teachers. Students would come up with the accepted scientific theory in a guided discovery environment where a teacher provides hints or clues (Crawford, 2000). Encountering differing students' opinions, students need to learn how to adjust their evidence from experimentation to support their own theories or refute others'. Reciprocally, students need to learn how they apply their theories to fit other evidence. How can those opportunities occur? The next review section describes how teachers can scaffold students to develop their scientific thinking skills through argumentation.

Teachers' Scaffolding Practices to Develop Students' Scientific Argumentation

Researchers have implied that students could develop the scientific thinking skills needed to understand the nature of scientific knowledge if teachers structured the classroom context and content appropriately to encourage students' argumentation (Driver et al, 1994; Kuhn, 1986). Driver et al. (1994) suggested that for students to adopt scientific ways of knowing, the roles of teachers are instrumental. One role for the teacher is to introduce new ideas or cultural tools and to support and guide students in making sense of these by themselves. Another role is to listen to students and determine the ways in which students explore activities beyond those assigned. The next section will discuss how students can develop their scientific thinking skills through the teacher's role of scaffolding in the classroom.

Hogan, Nastasi, and Pressley (2000) investigated the patterns of verbal interaction during peer-to-peer and teacher-to-student scientific sense-making discussions. They examined the teacher's role in student argumentation to find the relationship, if any, between discourse patterns and the sophistication of scientific reasoning in peer-peer and teacher-student discussion. The study included one eighth-grade teacher and his 12 students for 12 weeks, working on a unit about the nature of matter. There were four phases of instruction in the classroom: a teacher's demo, student group work, whole class discussion, and application of one consensus-model to explain new observations.

Data came from the second phase of instruction, group work, which included 16 group discussions amounting to approximately 10 hours of conversations, which were transcribed for fine-grained analysis. There were seven different steps used in analyzing the data. First, modes of discourse were coded, with three codes emerging: (a) *knowledge construction*, both peer and teacher-guided; (b) *logistical*, or concrete aspects of the task such as what color markers were used for the overhead; and (c) *off task* having nothing to do with the task. Second, codes for types of statements were developed, with three categories: (a) *conceptual statements* such as observations, ideas, conjectures, inferences, and assertions about the nature of matter; (b) *questions* and queries; and (c) *meta-cognitive statements* of three types—regulatory (regarding direct action on the task), evaluative (about the group's degree of progress or understanding), and standards-based (on the nature and goals of the task).

Third, discourse maps were created and compared based on the knowledge construction among peers or between the students and the teacher. Fourth, three types of interaction patterns were discerned: consensual, responsive, and elaborative. Fifth, conceptual proposition maps were created to assess the quality of the groups' thinking about each topic. The conceptual proposition maps restructured the sequential flow of the conversations into a conceptual flow. Sixth, the sophistication of students' thinking about a given topic, as represented by the conceptual proposition maps, was judged using a reasoning complexity rubric, which included generativity, elaboration, justification, explanation, logical coherence, and synthesis. For the last step of the analysis, groups' patterns of interaction were related to the reasoning complexity they achieved. That is, codes for statement types, interaction patterns, and reasoning complexity were compared to one another in peer groups and in student-teacher groups.

Overall, peer groups scored higher than teacher-guided groups on most criteria on the reasoning complexity rubric. Hogan, Nastasi, and Pressley (2000) interpreted that the more social structure of peer groups allowed more conductive idea generation and elaboration as well as justification of ideas. Peer groups also attained higher scores in synthesis of ideas than teacher-guided groups. Only explanation emerged at higher levels during teacher-guided discussions. The authors noted that most students' contributions to a discussion with a teacher were conceptual, reflecting the predominance of the teachers' role as questioner and the students' roles as respondents. The teachers were clearly in control of the discussion but did not dominate the interactions with students.

The role of a teacher was to create situations for students to expand and clarify their own thinking. The teacher prompted for and clarified students' ideas through questions and used their ideas to meet the goal of the lessons. The teacher did not evaluate students' ideas explicitly, so questions and responses could be built up without the closure of an evaluation, leaving synthesis up to the students. That is, students in teacher-guided groups more often stood back to allow interactions to occur between the teacher and one student at a time, allowing the other students to explore the full potential of collective ideas.

Hogan, Nastasi, and Pressley (2000) did not conclude that students in teacher-guided groups developed much higher level reasoning skills than those in peer groups. Instead, the authors concluded that the active social structure of peer groups allowed students in those groups to conduct more ideas involving generation and elaboration, as well as justification, than in teacher-guided groups. In teacher-guided groups, the task was accomplished mostly by the teachers' progressive questioning and prompting for thoughtful student responses. Actually, in peer groups, intellectual tenacity made the groups continue to confront difficulties in resolving issues with ill-informed ideas. Hogan, Nastasi, and Pressley (2000) implied that the key process for maximizing and expanding students' cognitive resources was through discourse in which students acknowledged, built upon, and elaborated on others' ideas, assisted by the role of teachers.

The study by Hogan, Nastasi, and Pressley (2000) concluded that the types of reasoning criteria were developed differently in peer groups and teacher-guided groups. They did not say that students in teacher-guided groups attained higher reasoning skills; instead, the roles of teachers could help the students develop their cognitive reasoning skills easily without failure to reach an outcome.

Watson, Swain, and McRobbie (2004) also investigated eighth graders' discussions with two teachers, looking at both teacher-centered and student-centered discussions to see how students developed their claims and how they justified them through argumentation. The results of this study support the importance of a teacher's role as a facilitator or catalyst that we found in the study by Hogan, Nastasi, and Pressley (2000). The teacher in a teacher-centered classroom emphasized a routine approach towards scientific inquiry, whereas the teacher in a student-centered classroom encouraged students to come up with their own ideas but failed to challenge the students to justify their ideas. Here again, the authors implied that the role of teachers holds high potential for developing students' cognitive reasoning skills using the appropriate pedagogy. The teacher's presence as well as teaching type, teacher-centered or student-centered, were both found to influence the development of students' argumentation. The next study describes a teacher's self-designed instructional curriculum as another factor impacting opportunities for student argumentation in promoting students' scientific reasoning skills.

Van Zee and Minstrell (1997) emphasized the use of reflective discourse rather than traditional classroom discourse in creating opportunities for students to understand the nature of scientific knowledge. To analyze an example of reflective discourse, van Zee, the researcher, used transcripts of class discussions to derive a description of the characteristic features of reflective discourse used by the teacher, Mr. Minstrell, compiling the data from two lessons with 25 to 30 high school students.

The author analyzed the two lessons using Mr. Minstrell's intentions as his guide, focusing on the functions of his utterances rather than on the students' thinking. The content of the two lessons included the nature of gravity and its effects. Van Zee and Minstrell (1997) developed some features of reflective discourse based on Minstrell's discussions with students.

First, Mr. Minstrell viewed himself as a helper for students to identify themselves as competent "sense makers" in the domain of physics. The teacher started with statements that constructed identities for his students as persons who already possess useful knowledge. The teacher also envisioned himself as developing shared ideas with students through negotiation, rather than transmitting information or confronting misconceptions.

Second, Mr. Minstrell followed the students' lead in thinking. The teacher elicited further elaboration of students' ideas instead of evaluating their responses and moving on to the next issue. The teacher summarized the students' prior statements in a neutral manner and avoided indicating whether the response might be considered right or wrong. The teacher also used reflective questioning to request clarification, rationale for a particular view, commitment, or verification. The authors defined these four components as reflective toss, which helped students engage in functions important in negotiations. In addition, typical speaking patterns of conversation, such as saying "OK" or "all right" or using silence played a role in allowing students to interact with each other during negotiation.

Third, Mr. Minstrell structured the discussion to foster and monitor changes in student conceptions. The teacher helped students to construct their identity for themselves by structuring the context, so that students explored their own thinking. The teacher solicited students' initial conceptions, structured the discussion to separate supporting comments and conflicting ones, and engaged students in monitoring changes in their thinking.

Van Zee and Minstrell (1997) concluded that reflective discourse was possible with the teacher documenting the ideas with which students began their study of physics and designing activities that focused on students' understanding. Based on these findings, the authors implied that the development of curriculum should help teachers shift toward more reflective practices.

Yerrick (2000), acting as researcher and teacher, examined the effects of open inquiry instruction with low-achieving high school students using the content of physics. Yerrick defined the importance of student's argumentation from two theoretical perspectives; one perspective, based on Toulmin's (1958) approach, presumes that arguments are shaped wholly by their rational and deductive nature. The other perspective accounted for differences in arguments by looking at social characteristics of group members. Based on this theoretical background, the author, Yerrick, acting as a volunteer teacher for 18 months, examined five low-level high school students' argumentation, which was observed to shift toward understanding the nature of scientific argumentation.

Yerrick (2000) collected interviews from five lower track high school students before and after his instruction to investigate changes in how tentative these students' knowledge claims are, what constitutes scientific explanations for lower track students, and if they believe they can answer a scientific question. Yerrick designed a curriculum for students centered around gathering evidence and proposing models and explanations about everyday events. First, students were to pose hypotheses with supporting evidence, proposing models or explanations. Second, students were to design and carry out experiments in groups of three to test their claims. Third, all students were to discuss their models or initial claims with the whole class, which ended in one of two ways: either the students agreed to accept the model or they returned to the lab for more evidence. To develop a discourse community without a teachers' authority over correct answers, Yerrick promoted the notion that the students' questions and experiences were to be valued first, and critique of those ideas was understood to be a subsequent necessity for communal understanding of any problem.

Yerrick (2000) analyzed students' interview responses before and after instruction, examining their discourse through the lens of Toulmin's argument approach. In the beginning of the lesson, the students as participants were found to have beliefs that there were singular answers and that they should know what these singular factual answers are before the instruction. After Yerrick's instruction, however, the students offered more tentative and sophisticated answers and they constructed their explanations by linking evidence to warrant. Furthermore, when they were asked how they would know if they were right, students all referred to the body of evidence that tests would produce. Based on these results, Yerrick implied the necessity of many efforts and a variety of approaches to appropriating scientific discourse in a classroom context, through teachers' scaffolding with questions like, "How do you know?" and "What do you think about Tom's idea?"

The two studies by van Zee and Minstrell (1997) and Yerrick (2000) described how teachers as researchers in these studies provided students with opportunities to develop scientific argumentation under certain self-designed inquiry instructional models. The teachers who participated in these studies held the knowledge of what scientific argumentation is and how teachers can help students demonstrate their reasoning skills while they develop scientific argumentation, which made it possible for teachers to implement these methods successfully in the classroom.

Summary: Teachers' Scaffolding Practices to Develop Students' Argumentation

Four research articles were reviewed to show how teachers influence the development of students' argumentation. Hogan, Nastasi, and Pressley (2000) investigated the quality of students' reasoning skills developed through argumentation with a teacher in teacher-guided groups and without a teacher in peer groups. The free social structures in peer groups allowed students to develop the far-ranging reasoning skills of justification, generativity, and elaboration. In teacher-guided groups, however, the teacher's role of scaffolding through questions or prompts made it possible for students to expand and clarify their own thinking to meet the goal of lessons. Students' responses could accumulate without the closure of an evaluation, leaving more interactions for students to synthesize and allowing students to explore the full potential of collective ideas.

Watson, Swain, and McRobbie (2004) investigated two eighth-grade classrooms with two different types of teaching styles: one teacher-centered and the other student-centered. It was suggested that students in the student-centered classroom could develop their own ideas as knowledge claims but fail to justify their claims with their own evidence from experimentation, whereas students in the teacher-centered classroom just did routine scientific processes without opportunities for argumentation. These two studies, Hogan, Nastasi, and Pressley (2000) and Watson, Swain, and McRobbie (2004), emphasized the importance of teachers' roles of scaffolding in the classroom to create students' opportunities for argumentation through which they could develop scientific reasoning skills.

Van Zee and Minstrell (1997) and Yerrick (2000) investigated how teachers, then, could provide more explicit instruction in order to give students opportunities to develop their reasoning skills through argumentation. The authors in these two studies participated as observers and teachers, and implemented their designed curriculum with background knowledge about the learners and the explicit instructional strategies. Instructional practices found common to these two studies were (a) that teachers viewed themselves as helping students to enact identities as competent "sense makers" in developing their own ideas, posing hypotheses with supporting evidence, and proposing models or explanations; (b) that teachers followed the students' lead in the thought process without evaluating students' responses; and (c) that teachers structured the lesson context to foster and monitor changes in student conceptions. However, these instructional practices found in these two studies cannot be generalized as guides for teachers to use, since the authors implied that the socio-cultural context outside the classroom could play a potential role in creating an environment for students' argumentation.

Discussion and Conclusion

The literature review in this chapter examined the general knowledge found in research papers about scientific argumentation in the context of scientific inquiry. First of all, the research revealed that scientific inquiry by students is different from that of scientists (Gallagher & Tobin, 1987; Krajcik et al., 1998). Students did not have opportunities to develop their own reasoning skills, such as connecting their data to the conclusions and framing research questions related to their content area. To solve this problem in implementing scientific inquiry in the classroom, studies investigated students who were given more opportunities to redesign their experiments, deal with anomalous data during experiments, share their ideas with the experts in the community, and develop their data from experimentation to the conclusion with the help of teachers (Crawford, 2000; Keys & Kennedy, 1999). Crawford (2000) and Keys and Kennedy (1999) emphasized the importance of teachers' roles of scaffolding to help students understand the nature of scientific inquiry. Maor and Taylor (1995) added that teachers who had constructivist epistemology could provide more opportunities for students to explore their own thinking process while they were collecting data and connecting their supporting or refuting data to the conclusions.

Besides teachers' roles of scaffolding for student argumentation, Toth, Suthers, and Lesgold (2002) and White and Frederiksen (1998) developed the explicit functional model, *Explicit Reflective Assessment*, to provide students with opportunities to demonstrate their thinking skills during scientific inquiry processes in the classroom. Through the reflective assessment, students had chances to check if their research questions were embedded in the content that they were learning, if their data reflected the research questions, if their results came from their collected data, and if their conclusions were supported by the results.

Scientific inquiry is not guaranteed to occur using hands-on activities only, which focus on procedural skills. Scientific inquiry is characterized by minds-on activities, which focus on reasoning skills, as well as hands-on ones (Driver, Newton, & Osborne, 2000; Newton, Driver, & Osborne, 1999; Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000; Vellom & Anderson, 1999). The authors in these studies argued that there had been little chance for students to understand the nature of scientific knowledge in the classroom. The authors, however, implied that the teacher could create an environment, through the use of questions and hints, in which students could develop skills in argumentation by expressing alternative ideas and using evidence to support their own ideas or to refute others'.

For the purpose of developing students' argumentation, the social context of group work was found to hold the potential to create a learning environment where students could explore their own and others' alternative ideas and develop reasoning skills regarding how they used data or evidence to support or refute ideas (Alexopoulou & Driver, 1996; Herrenkohl et al., 1999; Richmond & Striley, 1996). Furthermore, the type of leader in each group was another factor that facilitated the development of students' argumentation. *Inclusive leaders* often asked group members for their reactions to or opinions about an idea.

Students develop the scientific thinking skills needed to understand the nature of scientific knowledge while they practice argumentation in the classroom. Scientific thinking skills are defined as students' abilities to differentiate theory from evidence or vice versa and to coordinate them by adjusting one to the other (Reif & Larkin, 1991; Dunbar and Klahr, 1989; Kuhn, 1989a; Chinn & Brewer, 1993). The authors in these studies argued that students do not have the same reasoning skills to practice and understand science as scientists do in their research. However, students need to have opportunities under a teacher's guidance to practice differentiating evidence from theory and collecting evidence to support their own theory or refute the theories of others, in order to develop the reasoning skills needed to understand the nature of scientific knowledge. The aforementioned authors implied that the teachers' engagement in developing students' argumentation is critical.

Hogan, Nastasi, and Pressley (2000) investigated students' argumentation in four different groups with and without a teacher. Most students' contributions to a discussion were conceptual with a teacher in the group, reflecting the predominance of the teachers' role as a questioner. The role of a teacher was to create situations for students to expand and clarify their own thinking. The teacher prompted and clarified students' ideas through questions and used their ideas to meet the goal of the lessons. The teacher did not evaluate students' ideas explicitly, so questions and responses could be built up without the closure of an evaluation, leaving synthesis up to the students.

Watson, Swain, and McRobbie (2004) investigated eighth graders' discussions with two teachers using two different teaching approaches, one teacher-centered and one student-centered. The teacher in the student-centered classroom was found to encourage students to come up with their own ideas. Two studies, by Hogan, Nastasi, and Pressley (2000) and Watson, Swain, and McRobbie (2004) investigated the different outcomes in students' argumentation between the presence and absence of teachers and between two teachers in a teacher-centered and a student-centered classroom. The authors did not examine the instructional process of how teachers facilitated and what kind of teaching strategies they used for students' argumentation.

The researchers, as action researchers, designed curricula that featured more explicit instructional practices for this purpose of creating student opportunities to develop reasoning skills through argumentation (van Zee & Minstrell, 1997; Yerrick, 2000). The authors, Minstrell and Yerrick, acting as teachers and researchers, implemented explicit instructional strategies and facilitated students' argumentation to develop scientific reasoning skills. The instructional strategies from the curricula they designed had some common features. First, teachers helped students to pose hypotheses with supporting evidence to propose models or explanations. Second, teachers did not evaluate students' responses. Third, teachers structured the lesson context to foster and monitor changes in student conceptions.

The results of the research studies about scientific argumentation in the context of scientific inquiry provide preliminary evidence that it is essential for students to have opportunities for scientific argumentation with the help of teachers. Most researchers in this chapter, however, focused on investigating the nature of students' argumentation rather than the nature of teachers' explicit instructional strategies to see how teachers' instruction supported the opportunities of students' argumentation in the classroom.

The instructional strategies cannot be generalized for teachers to use, since those explicit instructional strategies need to be modified appropriately to different levels, such as to elementary or high school classes, or to different classroom contexts. However, it is necessary for researchers to investigate more closely how teachers use typical or specially designed instructional strategies or models for scientific argumentation in certain classroom contexts. This concern developed one research question in this study: *What kinds of instructional strategies are emerging when the teacher scaffold students' argumentation to develop scientific knowledge?*

It is also essential to study teachers' knowledge about scientific argumentation to better understand their explicit instructional strategies in the classroom. Based on researchers' understandings about the relationship between teachers' practices and their knowledge, there must be a consistent relationship between these two if teachers have firm and developed knowledge about scientific argumentation. Most studies reviewed in this chapter focused on the students' outcome from argumentation rather than teachers' practices of scientific argumentation, without enough information about teachers' knowledge about scientific argumentation. However, Minstrell and Yerrick worked as researchers and teachers in their studies (van Zee & Minstrell, 1997; Yerrick, 2000), so they could provide theoretical background reflecting their understandings of scientific argumentation. This concern developed another one of the research questions: *What is the teacher's knowledge about scientific argumentation?*

Finally, the relationship between teachers' teaching practices and students' abilities to demonstrate scientific argumentation became one of the concerns to be studied. Only two studies in this review, van Zee & Minstrell (1997) and Yerrick (2000), provided evidence of how students could develop argumentation in response to teachers' explicit instructions to some degree. However, students' scientific argumentation was not analyzed through the well-developed instrument, limiting the use of a qualitative approach to analyze students' argumentation. The more structured analysis of students' discourse by teaching strategies led to develop the last research question: *How do students respond t0 the teacher's teaching strategies for scientific argumentation?*

Based on the previous theoretical background about scientific argumentation in the context of scientific inquiry, this study explores one science teacher's instructional strategies as well as his knowledge about scientific argumentation.

CHAPTER III

DESIGN AND METHOD

Introduction

This chapter describes methods for collecting data on teaching strategies used to develop student argumentation skills and on student responses to those strategies. Scientific inquiry requires students to develop process skills such as scientific reasoning and critical thinking in order to develop their understanding of science (NRC, 2000, p. 18). Understanding scientific inquiry entails knowing how and why scientific knowledge changes in response to new evidence, logical analysis, or modified explanations debated within a community of scientists (NRC, 2000, p. 21). This understanding can be in part developed through classroom discourse in the form of scientific argumentation.

To analyze the development of scientific inquiry in the classroom, research has examined students' opportunities to use scientific argumentation, which helps students develop the ability to both use and understand scientific inquiry. However, the research has focused mainly on analyzing students' argumentation to see how well students can develop scientific claims and adjust those claims with data collected from experiments performed in the classroom. A reasonable next step is to examine how teachers' explicit instructional strategies can facilitate the development of students' reasoning skills through argumentation. Students' scientific argumentation in response to teachers' explicit teaching strategies is investigated here using pre-existing argument analysis tools (Toulmin, 1958; Jimenez-Aleixandre, Bugallo-Rodriguez, & Duschl, 2000; Hogan, Nastasi, & Pressley, 2000).

The purpose of this study was to examine certain explicit instructional strategies employed by one teacher to give students opportunities for scientific argumentation. This teacher scaffolds students to develop their scientific reasoning skills, such as being able to differentiate data from theory and coordinate both data and theory by adjusting one to the other. In addition, the teacher's knowledge about scientific argumentation was investigated to understand his teaching strategies better. Students' abilities to develop argumentation using the teacher's instructional strategies were also investigated. The research questions guiding this investigation were as follows:

1. What is the teacher's knowledge about scientific argumentation?
2. What kinds of instructional strategies emerge from a teacher's scaffolding of student discourse using argumentation?
3. How do students respond to these strategies?

Methodology

This investigation employed a case study method to answer research questions of interest. This case study includes two analyses. One is the analysis of the teacher's practices in creating opportunities for students to develop scientific argumentation skills, based on classroom observations. The teacher's physical practices of explicit teaching strategies were analyzed to describe the effects of explicit teaching practices on students' argumentation. The other is an in-depth analysis of student discourse in response to those teaching practices. This study combined methods from prior studies of students' argumentation skills, including Toulmin's (1958) approach to analyzing discourse logically, the *Epistemic Operation* used by Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) to analyze discourse sociologically, and the *Reasoning Complexity* framework used by Hogan, Nastasi, and Pressley (2000) to analyze discourse psychologically, which featured students' discourse as argumentation.

Data Collection

There were three phases of data collection with a sample selection. This study included the data only from the case study of one teacher's explicit teaching practices and his students' discourse, detailing how that teacher scaffolds students to develop their scientific argumentation.

In the first phase (see Figure 1), the researcher contacted nine science teachers by purposive sampling method. The researcher explored those teachers' knowledge about and teaching strategies for students' scientific argumentation through semi-structured interviews. In the second phase, the researcher observed a lesson that each teacher had selected as their best science lesson, containing much student interaction. In the third phase, the researcher selected one teacher, Mr. Field, for further analysis of his teaching practices and his students' argumentation. A case study was developed through classroom observations and interviews for ten weeks. More information about the data collection for each phase is provided as follows.

First Phase of Methodology

A pool of candidate teachers was identified based on their skills in engaging students in discussion and critical evaluation of scientific evidence and theories.

Because the topic of this research was not often directly addressed in classroom instruction, it was necessary to interview and observe several teachers to identify one who actively engages students in developing argumentation. The researcher contacted science teachers, using a purposive sampling method, who were recommended by science educators or whom the researcher had worked with over the last three years in workshops at the Scientific Inquiry Summer Institute.

Contact nine teachers by purposive sampling
Collect demographic information
Semi-structured interview on knowledge of scientific argumentation
(July and August, 2004)

↓

Class observation for each participant
(Sept., 2004)

↓

Select one teacher based on understanding of scientific argumentation
Contact to get information about the teacher
Classroom observation
Semi-structured interviews
Develop a case study
(Oct. and Nov., 2004)

↙ ↘

Analysis of teacher's practices   Analysis of student discourse

Figure 1: The time line with the sample selection

It was important to find science teachers who were interested in implementing scientific argumentation to help students learn science as inquiry and who had a strong understanding of the nature of scientific argumentation. For the purpose of finding the best candidate, nine science teachers were contacted by purposive sampling method. The researcher had worked for several years with science teachers from grades K-12 in workshops, conferences, and projects for several years. The researcher contacted science teachers from the fifth to eighth grade levels whose students are between the ages of 10 and 14, the age at which students are believed to begin to develop key abilities to do and understand scientific inquiry (Carey et al., 1989).

All of the selected teachers are members of the Oregon Science Teacher Leaders Institute, which represents science leaders in each county with the goals of teaching and learning science as inquiry. In addition, those teachers had participated in the Scientific Inquiry Summer Institute for the last three years in a sequence (2002, 2003, 2004), which was supported by institutes such as the Oregon Department of Education, Department of Science and Mathematics Education, and the Oregon Science Teachers Association. The teachers are interested in chances to learn science content and pedagogical skills to promote teaching and learning science as inquiry. The process of selecting several participants and finalizing one participant for further investigation is explained below.

First, the researcher attended The Third Annual Oregon Science Teacher Leaders Institute, held July 28–30, 2004 at the Linfield College Campus in McMinnville, Oregon, either as a staff member or as a participant. The year's theme was *Analyzing* *and Interpreting Scientific Inquiry.* During the workshop, the researcher met science teachers at all levels, from elementary to high school, and had the opportunity with them about scientific inquiry. Science teachers asked about this study and the researcher described it, defining scientific argumentation briefly if needed. However, the researcher did not describe the purpose of the research, nor ask teachers to be participants in this study at that time. The reason for attending the workshop at Linfield College during July 2004 was not to find participants but to become accustomed to talking to science teachers for the purposive sampling method.

Then, the researcher contacted science teachers who had been participants in the workshop held by Oregon Science Teacher Leaders Institute for the last three years by purposive sampling method. The researcher contacted nine science teachers by email or phone after this workshop and asked if they were willing to be participants in a study of scientific argumentation. During this process during August, 2004, the researcher described the purpose of the investigation, methods, instruments, risks and benefits (Appendix A: Initial Query). If teachers showed interest in this investigation, the researcher then scheduled an interview first at their school site. The interview lasted thirty minutes under semi-structured protocols, asking about teachers' general understanding of scientific argumentation as well as scientific inquiry.

Before the interview, those selected teachers were given *The Informed Consent Document* (Appendix B), which describes the purpose of this project and asks for their participation as volunteers. Participants were also given a copy of *The Informed Consent Document* to keep. Once the selected teachers signed up to participate, the researcher interviewed them with protocols asking about their knowledge and understanding of scientific argumentation. To develop interview protocols, the researcher worked with science educators in the Department of Science and Mathematics Education at Oregon State University to see if those protocols were appropriate to capture teachers' knowledge about students' scientific argumentation and their explicit teaching strategies. As interviews went on, protocols were added and modified as needed to facilitate our conversation and to meet the goal of this study. For example, when one teacher talked about their specific designed inquiry activities or curriculum, the researcher added more protocols to get information about how the teacher assessed students' reasoning abilities for scientific argumentation and if there was a good example of a successful argumentation case in the classroom. All interviews were audiotaped to be transcribed later.

Second Phase of Methodology

After the initial interviews, the researcher scheduled observations of classes of nine teachers during September 2004 when the new academic year started, but only six teachers participated in class observation. Those teachers were observed only once each to see how they provided students with opportunities to develop scientific argumentation. At this time, one video camera with a wireless microphone to capture the teacher's voice clearly was employed during class observations. This video camera was set up at the corner of the classroom and recorded the teachers' practices and voice only. The wireless microphone attached to the teacher during the observation did not record students' voices unless they were close to the teacher.

Those nine participating teachers selected one best lesson so that the researcher could observe explicit teaching strategies that provided students with opportunities to develop scientific argumentation. Class observations focused on teachers' explicit teaching strategies to see how the teachers scaffolded students to develop scientific argumentation, such as by using questions, hints or clues during their teaching. The teaching strategies employed by teachers were related to their knowledge about scientific argumentation to see in what ways they implemented opportunities for argumentation during the lesson. Observational protocols from OTOP (OCEPT-Teachers Observational Protocols; Appendix C) were used in observing teachers' teaching strategies in the context of scientific argumentation.

The OCEPT (Oregon Collaborative for Excellence in the Preparation of Teachers) research team designed the observational protocols, OTOP, to analyze teachers' reform-based teaching. The OTOP contains ten items for effective teaching strategies envisioned in the *Standards* (NRC, 1996, 2000). The use of the OTOP tool revealed the teaching profile of scientific argumentation that emerged during the class observations in this study, which was then used as one of the criteria to select the one teacher for further investigation. The field notes were taken during observations, focusing on what questions and prompts teachers used for creating students' opportunities for scientific argumentation.

The first data collected through interviews provided a lens through which the researcher observed teachers' explicit verbal and physical practices to see how they implemented scientific inquiry based on their knowledge about scientific argumentation. Those observations occurred once for each participant and lessons were videotaped and audiotaped to document the features of the teaching strategies, showing both verbal and physical interaction between teachers and students. On the basis of the recorded instructional practices, the researcher discussed with another science educator whom to choose as the final participant for further investigation.

Therefore, the data collected from interviews with teachers enabled the researcher to decide what to look for during the class observation, and the data from interviews and class observations guided the researcher in selecting only one teacher for further investigation, which occurred during October and November, 2004, and made up the main part of this study.

Third Phase of Methodology

On the basis of the interviews and class observations with the nine teachers, Mr. Field was selected for further study. The criteria to finalize the one teacher were discussed with one science educator to construct the validity of data collection. The criteria employed in selecting one teacher for further investigation included: (a) knowledge of scientific argumentation as well as scientific inquiry defined by Kuhn (1989) and Driver, Newton, and Osborne (2000); (b) evidence of teaching strategies employing students' scientific argumentation, such as using questions or prompts that encouraged students to express their own ideas, captured through class observations with the use of OTOP and field notes; and (c) his current attendance of professional development programs with the purpose of developing and designing teaching strategies about scientific inquiry.

The selected teacher, Mr. Field, signed up for participation in the *Informed Consent Document* (*teacher form;* Appendix D). Mr. Field agreed to participate in this study. Then, Mr. Field contacted his principal for investigation permission, and the principal sent all IRB documents to the superintendent of his school district for permission to participate. When the finalized agreement from the superintendent was received, the researcher scheduled time to talk about this study with Mr. Field's students. Mr. Field distributed the *Informed Consent Document* (*parent form;* Appendix E) for students to take home to get their parents' permission and the *Assent Document* (*student form:* Appendix F) to get the students' agreement, indicating that they understood the goal and the process of this study clearly. After all documents were signed, the researcher visited Mr. Field's classroom every day for one week to understand the classroom context and the nature of the students as well. During the week the researcher visited, the metric system was being studied and students were observed to develop argumentation through activities done as individuals or in groups.

Then, Mr. Field and the researcher shared information about which lessons should be observed, the kind of lab activities students would do, the types of discussion that would occur during the unit (small groups, whole class, or group presentations), and the teaching strategies Mr. Field would implement. Mr. Field selected two units on "Newtonian Laws": three-week units using the specific teaching strategy *Claim-Evidence Approach.* Mr. Field was confident that the approach would give students opportunities to develop argumentation with the goal of cognitive and content development. This unit included several lessons consisting of students' exploration and teacher's demonstration during pre-lab activities, the students working in groups during lab activities, and whole class or group presentations during post-lab activities.

In each class observation, the researcher employed one video camera to record the teacher's and students' verbal and physical practices, and three audio recorders, to record students' voices in their groups. Three audio recorders were set up on three different tables to record students' voices when they started to discuss any issue. During each class observation, the researcher used observational protocols from OTOP (OCEPT-Teachers Observational Protocols) to see how Mr. Field provided students with opportunities for scientific argumentation. The OTOP has ten items describing how the teacher interacts with students verbally and physically. Out of ten items, OTOP items #4, #5, #6, and #7 are especially related to the teacher's teaching strategy and students' opportunities to express their ideas in arguments.

While taking field notes, the researcher recorded the teacher's and students' discourse as evidence for scientific argumentation. For example, what kind of questions or prompts does the teacher use? What are the students' responses to those questions and prompts? Field notes describing the physical classroom context were also taken on location. For example, the researcher recorded what lessons or part of lessons during each observation included valuable data to be transcribed later for the data analysis, which allowed the researcher to select the argumentative lessons out of the total lessons.

To summarize the methods of data collection, the researcher collected (a) interview data lasting thirty minutes from nine participants in the first phase, (b) six classroom observations out of nine in the second phase, (c) 18 hours of preparation time over two weeks to gain familiarity with students and classroom context without data collection, and (d) sixty hours of data collection over six weeks through class observations and two more interviews with the teacher only. In addition to verbal data recorded from Mr. Field and his students, students' two different lab reports were collected for more evidence of students' abilities to develop scientific argumentation. The brief conversations with Mr. Field and his instructional memos during the study were also used as one method of "triangulation" of the data, which means that many sources of data are better than a single source because multiple sources lead to a fuller understanding of the phenomena in the context of this study (Bogdan & Biklen, 1998).

Instruments

Interview Protocols

First, the researcher collected teachers' demographic information and interviewed them about their knowledge about scientific argumentation using the semi-structured interview protocols. Those protocols for understanding scientific argumentation included:

1. How do you define scientific inquiry in your classroom?
[I expect that participating teachers can understand that scientific inquiry is NOT just to follow the procedures given by them, since these teachers have discussed with science educators what ideal scientific inquiry is in the classroom, through workshops, conferences, and projects.]

2. How does scientific inquiry differ from hands-on activities?
[Responses from teachers must indicate that those teachers can differentiate hands-on activities from scientific inquiry, which requires reasoning skills as well as procedural skills.]

3. How do students develop their reasoning skills during scientific inquiry?
[Participating teachers have certain knowledge of how students can develop their reasoning skills as well as procedural skills during scientific inquiry activities; here I can expect that teachers might mention certain strategies in

which students develop their reasoning skills, such as discussion time as a whole class or in group work.]

4. How do teachers support students to develop their scientific thinking? Do you have any specific or explicit teaching instruction or model that you designed for this purpose in the classroom?

[This question is asking for teachers' certain designed model or function for students to develop their scientific thinking.]

5. Have you experienced a critical moment in which you felt that students were successful in developing their scientific thinking or reasoning skills during scientific argumentation?

[This question is asking teachers to provide an example where they provided opportunities for students to develop their scientific thinking skills.]

6. What are the barriers preventing students from successful scientific argumentation?

[This question is asking about the limitation of pedagogical skills for students' scientific argumentation.]

7. What are your criteria for students successfully demonstrating reasoning skills?

[This question is asking if teachers have certain criteria that make teachers feel they scaffold students to demonstrate scientific thinking skills.]

Before using these protocols, the researcher contacted science educators to construct the content validity and discussed if those protocols were appropriate to capture the teachers' knowledge about students' scientific argumentation and their explicit teaching strategies. During the interviews with teachers, the researcher used these questions to learn how well they understood scientific argumentation and their teaching strategies.

Observational Protocols

Mr. Field, the finalized teacher, was observed for eight weeks using observational protocols, to analyze his teaching strategies for developing students' abilities to use scientific argumentation. The protocols were designed by the OCEPT research team, stressing the need for significant improvement not only in translation of content into instruction, but also in positive and encouraging student-teacher interactions from the perspective of K-12 teachers (Wainwright, Flick, & Morrell, 2004, p. 6). These protocols aimed to provide observational lenses, through which teachers' and students' behavior and verbal practices of scientific argumentation were captured. The instrument of OTOP (OCEPT-Teacher Observation Protocols) was adopted for use during the second phase while observing six teachers out of the original nine and during the third phase with Mr. Field. The observational protocols were as follows.

1. This lesson encouraged students to seek and value various modes of investigation or problem solving.
   [This indicates how teachers present open-ended questions for students to pose another question or share their ideas for investigation.]

2. Teacher encouraged students to be reflective about their learning.
   [This focuses on metacognition, students' thinking about their own thinking. Teachers can encourage students to explain their ideas through routine questions and students identify anything unclear to them.]

3. Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.

[This focuses on students' discourse and collaboration. Teachers can provide opportunities for group work and students worked collaboratively and exchanged their ideas with peers.]

4. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.

[This focuses on rigorously challenged ideas. Teachers challenge students' ideas and students provide evidence-based arguments by listening to peers or teachers critically.]

5. The instructional strategies and activities probed students' existing knowledge and preconceptions.

[This focuses on student preconceptions and misconceptions. Teachers assess students' thinking through questions and help them to build their knowledge on prior knowledge. Students can express various or incorrect ideas from others freely.]

6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.

[This focuses on students' conceptual thinking. Teachers can ask higher-level questions and encourage students to extend their ideas to the broader ones.]

7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.

[This focuses on students' divergent thinking. Teachers encourage students to challenge other peers or texts and students can generate alternative interpretations.]

8. Appropriate connections were made between content and other curricular areas.

[This focuses on interdisciplinary connections. Teachers integrate content with other curricula and provide examples from the real world connecting to the student's personal experience.]

9. The teacher/instructor had a solid grasp of the subject matter content and how to teach it.
[This focuses on teachers' pedagogical content knowledge. Teachers' information presented was accurate and appropriate to students' cognitive level and they can field students' questions in a way that encourages more questions.]

10. The teacher/instructor used a variety of means to represent concepts.
[This focuses on multiple representations of concepts. Teachers use multiple methods, strategies, and teaching styles to explain a concept.]

These observational protocols from OTOP focused on what kind of teaching strategies teachers used and how they scaffolded students to develop argumentation in the context of scientific inquiry. On the basis of the researcher's experience employing this tool for class observations, the OTOP items #4 (challenging ideas), #6 (conceptual change), and #7 (divergent thinking) scored highly in cases of much interaction between teachers and students during the lessons.

Data Analysis

Data analysis proceeded in two ways: (a) analysis of classroom observations regarding Mr. Field's teaching strategies, and (b) analysis of his students' discourse as responses to those strategies.

A Descriptive Analysis of Classroom Practices

First, the researcher coded Mr. Field's interviews to describe his understanding and teaching strategies about scientific argumentation using appropriate categories under the interview protocols. For the teaching strategies, the researcher employed the observational protocols to see how Mr. Field provided students with opportunities for scientific argumentation. Originally, the OTOP instrument designed by OCEPT had ten items with scales ranging from 0 (not observed) to 4 (most frequent). Through observations, a macro frame for describing Mr. Field's instructional strategies in each unit and a micro frame for describing each lesson were developed. The relationship between Mr. Field's knowledge about scientific argumentation and his teaching strategies was also examined.

The data gained from Mr. Field's interviews and classroom observations were used to develop the generic frameworks, supporting and facilitating argumentation in the classroom, with descriptions of each teaching strategy and its evidence during the classroom observation in a table. For example, one of the instructional strategies was called *Daily Science.* This was one of Mr. Field's teaching strategies, which he used to encourage students to develop different discourse skills. In the table, each teaching strategy found during classroom observations was described in more detail, such as its definition and how it was implemented in the classroom.

Mr. Field's teaching practices were also triangulated using OTOP profiles and his interviews. Each lesson—with a different teaching strategy, classroom context, and science content—displayed different patterns using the OTOP profile (See Appendix C). For example, OTOP #2 (Metacognition*),* #4 (Challenging ideas), and #7 (Divergent thinking) revealed that Mr. Field structured more questions and prompts, which encouraged students to express their different ideas. Mr. Field's verbal data from three semi-structured interviews were also used in triangulation to validate the findings about his knowledge and his teaching strategies for scientific argumentation.

A Detailed Analysis of Students' Scientific Argumentation

The students' discourse in groups or with the whole class was transcribed from audiotapes. This transcription shows students' responses to Mr. Field's instructional scaffolding. The main discourse was whole class discussion between Mr. Field and his students. Small groups of three or four students were also observed, but their discourse was not as productive in capturing some features of argumentation (Hogan, Nastasi, & Pressley, 2000; Watson, Swain, & McRobbie, 2004; van Zee & Minstrell, 1997; Yerrick, 2000).

To analyze students' efforts to reason scientifically during the whole class discussion, the researcher adopted the research methods of (a) Toulmin (1958) for the logical analysis; (b) Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) for the sociological analysis; and (c) Hogan, Nastasi, and Pressley (2000) for the psychological and pragmatic analysis. The researcher developed the Scientific Argumentation Table (SAT; Figure 2) containing three argument analyses. The SAT consists of two columns for the discourses by *Teacher* and *Student* and three columns for the argument analysis labeled *Toulmin, Epistemic Operation,* and *Reasoning Complexity,* with the topic given in the first row.

Topic/date				
Teacher	**Student**	**Toulmin**	**Epistemic**	**Reasoning**

Figure 2: Scientific Argumentation Table (SAT)

In the first row, there is the topic of the lesson covered. The first column included the teacher's discourse, such as questions, prompts, and clues that were helpful for students to develop their argumentation. In the second column was placed students' discourse as argumentation in response to Mr. Field's verbal actions. These two columns revealed who was dominating the discussion and who provided a lower or higher quality of argumentation during the lesson. In addition to the amount of discourse by Mr. Field and his students, the quality of argumentation was also analyzed with three different tools, located in the last three columns of the SAT: *Toulmin, Epistemic Operation,* and *Reasoning Complexity.*

Toulmin's Approach

Toulmin's logical approach (1958, Figure 3) was used to examine the students' abilities to think scientifically. Toulmin's approach (Figure 4) for analyzing argumentation includes six components: *Data, Claim, Warrant, Qualifier, Rebuttal,* and *Backing.*

Data	**Facts as evidence** from prior knowledge, observations or experimentation for the conclusions
Claim	**Conclusion** to be established
Warrant	**Rules that develop the relationship** between Claim and Data.
Qualifiers	Making Warrant **stronger** with merits
Rebuttal	Making Warrant **weaker** with not-merits
Backing	**General** conditions to the warrants.

Figure 3: Definition of Toulmin's Approach (modified by Young-Shin Park)

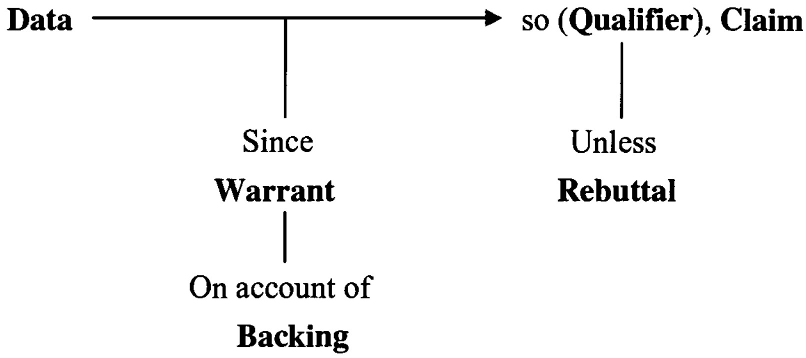


Figure 4: Toulmin's layout of arguments (Kelly et al., 1998)

On the basis of this approach, the researcher investigated how Mr. Field's and his students' discourse fits into these six components. This analysis displayed which component of Toulmin's approach was most frequently used in the interactions between Mr. Field and his students as they developed scientific argumentation. Then, the argument developed by Mr. Field and by his students respectively was compared to see who was dominating the interaction and who developed which argument component defined by Toulmin. This analysis enabled the researcher to describe student argumentation as more extended one or less extended one, depending on Mr. Field's teaching strategies and science content. In this study, the researcher selected 23 lessons out of 60 hours of class observations that included productive argumentation between Mr. Field and his students, and then coded each discourse using Toulmin's criteria. When the lessons included students' individual worksheets or lessons in which Mr. Field dominated, such as lectures, they were excluded from the data source. The lessons that included verbal interactions during group work or whole class discussions dealing with certain science content were selected for data analysis.

Epistemic Operations

The second dimension for analyzing arguments takes into consideration the students' social context. For this purpose, the researcher employed another type of analysis, *Epistemic Operations* (Figure 5) defined by Jimenez-Aleixandre et al. (1997, 1998, 2000), which was constructed from several sources, including history, philosophy of science, and classroom conceptual ecology. This analysis of discourse in the science classroom is the sociological approach (Jimenez-Aleixandre, Diaz de Bustamante, & Duschl, 1998), based on Pontecorvo and Girardet's research (1993). Pontecorvo and Girardet (1993) concluded that social interaction provides a social support system for the acquisition of procedural knowledge learned in the context of a cognitive apprenticeship.

Induction		Looking for **patterns**, regularities
Deduction		Identifying particular **instances of rules**, laws
Causality		Relation **cause-effect**, looking for **mechanism, prediction**
Definition		State the **meaning** of a concept
Classifying		**Grouping** objects, organisms according to criteria
Appeal to	Analogy	Appealing to **analogies, instances or attributes** as a means of explanation
	Exemplar/instances	
	Attribute	
	Authority	
Consistency	With other knowledge	Factors of consistency, particular (with experience) or general (need for similar explanations)
	With experience	
	Commitment to consistency	
	Metaphysical (status object)	
Plausibility		**Prediction or evaluation** of own/others' knowledge

Figure 5: Epistemic Operations for Student Argumentation (Jimenez-Aleixandre et al., 1997, 1998; 2000)

Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000) found that students used *Causality* more than other components of *Epistemic Operations* while they were developing their argumentation. However, their findings displayed students' discourse only, without teacher's prompts or input that could support students' opportunities to demonstrate their argument skills. In this dimension of analysis, the researcher coded each discourse element developed by Mr. Field and his students first, and then compared them to see who was developing more of which components of the *Epistemic Operations.* This analysis enabled an understanding of which sociological operations the students or Mr. Field used to develop their scientific argumentation respectively.

Reasoning Complexity

In the third dimension for analyzing arguments, *Reasoning Complexity* (Figure 6) was included in the last column of the SAT. *Reasoning Complexity* is defined by Hogan, Nastasi, and Pressley (2000) as containing six components.

Criteria	Operational Definition
Generativity	**Subtopics** brought forth within the discussion.
Elaboration	**Details** on the subtopics that are brought up
Justification	**How to use evidence** from their own experience, experimentation, or prior knowledge.
Explanations	The **presentation of mechanisms** that account for a phenomenon
Logical coherence	Logical coherence is **judged only when a justification or explanation is evoked**
Synthesis	**Disconfirming evidence,** which is a hallmark of dialectical and higher order thinking

Figure 6: Reasoning Complexity (modified from Hogan, Nastasi, & Pressley, 2000)

Hogan, Nastasi, and Pressley (2000) stated that the sophistication of students' thinking about a given topic is judged by its *Reasoning Complexity*, which describes the essential components of scientific reasoning. The first two categories, *Generativity* and *Elaboration*, specify the amount and type of ideas and elaborations of ideas within a topic unit. The second two categories, *Justification* and *Explanations*, specify the structure of students' reasoning, meaning how their ideas are supported and explained. Finally, the *Logical coherence* and *Synthesis* categories specify the quality of the students' thinking. These six criteria comprise a judgment of reasoning complexity (p. 396).

The *Reasoning Complexity* in Hogan, Nastasi, and Pressley (2000) was derived from Resnick et al. (1993), who developed a descriptive and analytic account of reasoning as it occurred in social settings based on the work of philosophers, linguists, and psychologists. Resnick et al. (1993) assumed that the structure of the discourse of reasoning depends significantly on the nature of the situation in which that reasoning is carried out and that some dimensions of the situation—such as social status of the participants, the goals of the group, the goals of each participant, and the content—tend to affect the course of reasoning. Like with the other two analysis tools, the discourse developed by Mr. Field and his students was coded to see which reasoning skills were most frequently used to develop their argument. In addition, different reasoning skills used by Mr. Field and his students to develop arguments were identified respectively depending on the teaching strategies and science content.

One example of the SAT (Figure 7) is shown following, containing the three argument analysis approaches. This SAT dealt with the content of Newton's third law at the seventh-grade level. Mr. Field interacted with students to develop background information before implementing the lab activity. On the basis of the pictures from the textbook about friction, Mr. Field discussed the topic with students. Each dialogue between Mr. Field and his students in each dimension of the SAT were coded first. The most frequently used component in each dimension was compared first. Then the differences in component usage in each dimension between Mr. Field and his students was identified, which provided an understanding of the quality of student argumentation.

Based on this analysis in each dimension, the relationship among the three dimensions was developed. That is, the majority of students' *Claims* (in the *Toulmin* column) were developed through *Deduction* or *Definition* operations in the *Epistemic Operation* column. Furthermore, those *Claims* were developed through the *Reasoning Complexity* elements of *Generativity* or *Elaboration.* This relationship among three different analyzing tools could allow for discussion and interpretation of Toulmin's argument components in terms of their sociological (*Epistemic Operation*) and psychological aspects (*Reasoning Complexity*).

In this SAT, four components of Toulmin's approach, *Data, Claim, Warrant,* and *Qualifier,* are more frequently used than the other two, *Rebuttal* and *Backing. Causality* is the most frequently used *Epistemic Operation* approach and *Justification* is most frequently used in *Reasoning Complexity.* Those developed patterns in each dimension and the relationship among those dimensions were related to Mr. Field's explicit instructional strategies, such as his prompts and questions.

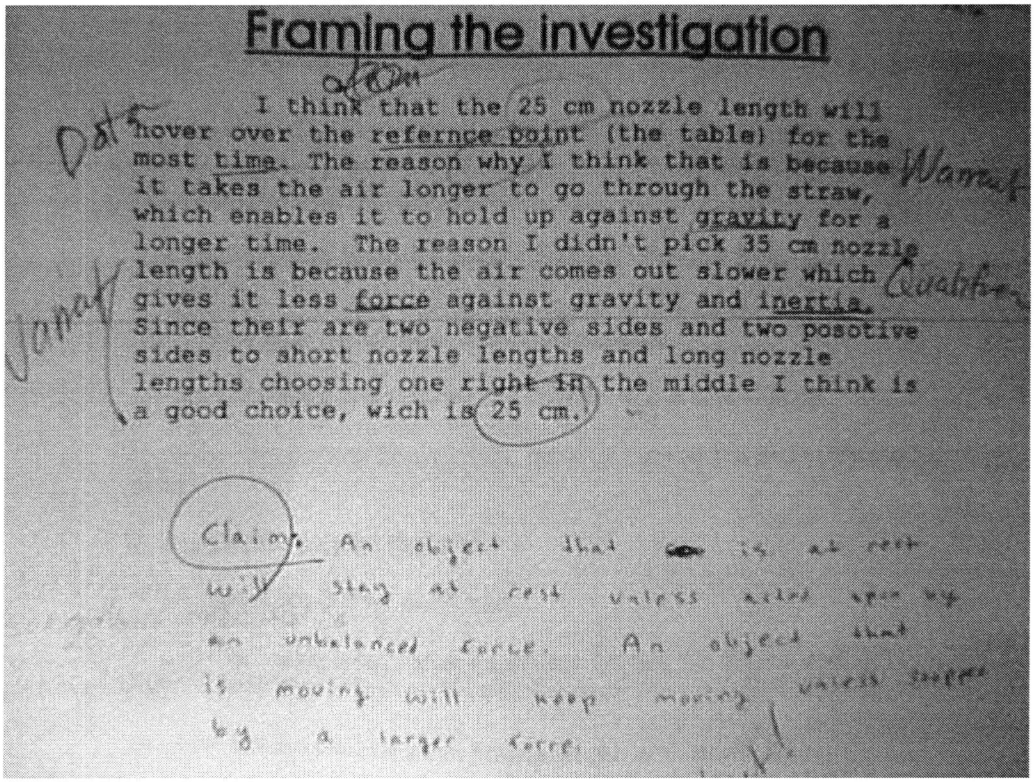
TOPIC: Newton's third law (action and reaction: about friction)
October 28, 2004 (4th Block)

TEACHER	**STUDENT**	**Toulmin**	**Epistemic**	**Reasoning**
have these wind suits that are also there to keep them warm. Does anybody see any frictions involved in this picture? Tyler?		Claim	Deduction	Generativity
	The [people] leaning against.	Data	Appeal	Elaboration
The snow there? OK, so he says the feet of the reindeer are specifically designed, and they are, to allow the reindeer to stand up against the loss of friction in the snow. They have sharp points to break into it. (1) They also have, in the middle of their hoof, they have a special type of pad that not only keeps their feet warm, but it also grips the snow.(2) That is a pretty amazing adaptation of the reindeer.(3) Does anybody see any other frictions involved there? (4)Yes?		Warrant	Causality	Justification
		Qualifier	Consist	Explanation
		Qualifier	Consist	Logical
		Warrant	Plausibility	Generativity
	The skis.	Data	Appeal	Elaboration
The skis, they are trying to reduce the friction as much as possible on the snow.(1) The deer are trying to increase their friction.(2) The men are trying to reduce the friction so that they have as little drag as possible.(3) This is a serious competition over there.(4) These guys are professional racers.(5) Their reindeer have been specifically bred to run long and fast.(6) There are lots of people that bet money on these races, just like horse racing or dog racing in the United States. (7) They are doing everything they can to try to reduce the friction.(8) What other friction do you see there that they are probably trying to reduce?(9) Victor?		Warrant	Causality	Justification
		Warrant	Causality	Justification
		Qualifier	Deduction	Explanation
		Qualifier	Consist	Logical
		Data	Consist	Logical
		Data	Appeal	Justification
		Claim	Appeal	Justification
		Claim	Causality	Justification
		Data	Causality	Justification
	The wind with the suits?	Data	Causality	Justification
Good the wind and that crouched position.(1) They are trying to reduce the wind drag as much as possible.(2) They know from experience that if they can form a wing shape, the air goes over the top of them with the least amount of drag possible.(3) Yes?	(1)	Data	Appeal	Elaboration
	(2)	Warrant	Causality	Justification
	(3)	qualifier	Consist	Logical
	Weight, (1) because if they have a lot of weight, then they will go into the snow (2)	Data	Appeal	Elaboration
		Warrant	Causality	Explanation
That's another good one, because we know about mass affects acceleration, doesn't it?(1) Very good. You came up with two very good ones there, Tyler. Probably these guys are very conscious about the weight that they carry, and they have a big strong match between their weight and their strength ratios, don't they? (2) Alright, let's go on to page 57.	(1)	Qualifier	Consist	Logical
	(2)	Qualifier	Consist	Logical

Figure 7: Sample SAT (The topic: Newton's Third Law–Friction)

In addition to student argumentation seen through class observations, students' lab reports were also analyzed using Toulmin's approach. There were two lab activities during the data collection period: (a) *Rocket Balloon Activity* based on Newton's first law, and (b) *Marble Activity* based on Newton's third law. The reason why only Toulmin's approach was employed to analyze written argumentation was that it did not reflect on the acquisition of knowledge that came through responses among participating students and the teacher in the social setting. Students' lab report writing was scored based on Mr. Field's model of the *Inquiry Guideline* with a full score being five; scores given by the researcher and Mr. Field were compared for validity. This result was used to examine the quality of individual student argumentation.

Figure 8 below shows how one student developed her own hypothesis or question based on her claim withdrawn from the textbook. The researcher scored each stage of inquiry by coding each written sentence using the six components developed by Toulmin. *Data, Warrant, Claim,* and *Qualifier*, but not *Rebuttal,* were found in students' predictions before their investigation.



Framing the investigation

Claim

I think that the 25 cm nozzle length will hover over the refernce point (the table) for the most time. The reason why I think that is because it takes the air longer to go through the straw, which enables it to hold up against gravity for a longer time. The reason I didn't pick 35 cm nozzle length is because the air comes out slower which gives it less force against gravity and inertia. Since their are two negative sides and two posotive sides to short nozzle lengths and long nozzle lengths choosing one ~~right in~~ the middle I think is a good choice, wich is 25 cm.

Data

Warrant

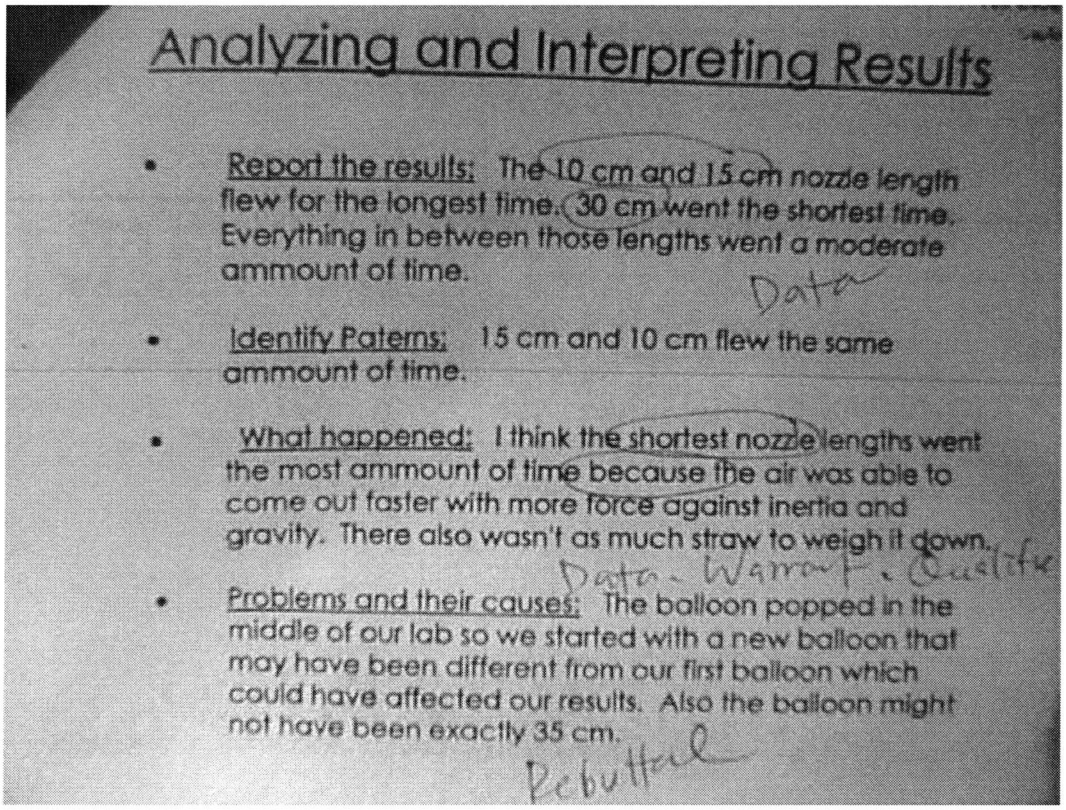
Qualifier

Warrant

Claim: An object that is at rest will stay at rest unless acted upon by an unbalanced force. An object that is moving will keep moving unless stopped by a larger force.

Figure 8: Student's lab report: *Framing the Investigation* part of the *Inquiry Guideline*

Figure 9 shows how that student analyzed and interpreted the results. The researcher found Toulmin's components of *Data, Warrant, Qualifier*, and *Rebuttal.* Here, *Backing* is the Newton's first law itself, so it did not show up in this lab report. The researcher scored this inquiry step with the full score of five and grouped all students' work into three categories: **Complete**, **Partial,** and **Limited**. The researcher's scoring system was validated by Mr. Field's scoring, with all lab scores being in agreement.



Analyzing and Interpreting Results

- Report the results: The 10 cm and 15 cm nozzle length flew for the longest time. 30 cm went the shortest time. Everything in between those lengths went a moderate ammount of time.

Data

- Identify Paterns: 15 cm and 10 cm flew the same ammount of time.

- What happened: I think the shortest nozzle lengths went the most ammount of time because the air was able to come out faster with more force against inertia and gravity. There also wasn't as much straw to weigh it down.

Data - Warrant - Qualifier

- Problems and their causes: The balloon popped in the middle of our lab so we started with a new balloon that may have been different from our first balloon which could have affected our results. Also the balloon might not have been exactly 35 cm.

Rebuttal

Figure 9: Student's lab report: *Analyzing and Interpreting Results* part of the *Inquiry Guideline*

The participating students' lab reports were used to examine the student responses to Mr. Field's explicit teaching strategies in order to see how students developed their arguments in a logical way in terms of written argumentation.

Validity and Reliability

In collecting data, the researcher worked with one science educator in the Department of Science and Mathematics Education to construct the content validity of interview protocols to capture teachers' knowledge about scientific argumentation. Questions were added or modified based on the science educators' feedback before teachers were interviewed. The researcher also listened to nine teachers' interviews repeatedly and coded them to develop the aspects of secondary science teachers' understandings about scientific argumentation. Then, the researcher discussed those categories with one science educator in order to select one teacher for further investigation in this study.

The final selected teacher's behavior and verbal practices, as seen in observations and interviews, were also discussed with the same educator regarding their validity. In using the OTOP developed by OCEPT, the researcher in this study is a reliable tool in collecting and analyzing data from research experiences for the last three years.

Finally, the researcher analyzed Mr. Field's and his students' discourse with the use of the Scientific Argumentation Table (SAT). The researcher employed three different approaches (*Toulmin, Epistemic Operation,* and *Reasoning Complexity*) for the analysis. One science educator as an inter-rater performed the same data analysis with one SAT; then, he and the researcher compared the same SATs, and they had 100% agreement in the *Toulmin* approach, 90% in *Reasoning Complexity*, and 80% in the *Epistemic Operation* approach. The discussion between the researcher and one science educator ensured the validity, and the researcher had the confidence to analyze the latter part of the data. Then, the researcher visited the beginning part of the data and re-analyzed it to ensure the validity and reliability of the data analysis. Finally, the researcher interviewed Mr. Field in an exit interview after analyzing the data to further construct the validity of the results of this study.

The Researcher

The researcher's role in this study is to collect and analyze data. As described earlier in this chapter, the researcher characterized and evaluated the participating teachers' understanding of and explicit teaching strategies about students' scientific argumentation, using interviews and observations. The researcher's personal conceptions of scientific argumentation have inevitably influenced these interpretations. For example, the procedures employed in this study required the researcher to make decisions whether participating teachers' responses about scientific argumentation matched the accepted understanding of scientific argumentation envisioned by science educators and science reform documents. Obviously, the validity of such decisions is dependent on the researcher's understandings of this currently accepted knowledge. A well-developed understanding of scientific argumentation is required to recognize and identify detailed aspects of scientific argumentation in participants' discourse and behaviors during the sequence of phases during data collection and analysis. Therefore, it is requisite to delineate the researcher's knowledge about scientific argumentation in the context of scientific inquiry to gain confidence in the researcher's abilities to interview participants, analyze and interpret data, and form conclusions from data.

The researcher in this study earned a bachelor's degree in Earth Science Education in her home country, Korea, and a master's degree in Science Education from the Department of Science and Mathematics Education, Oregon State University. For her master's project, the researcher compared Korean science teachers' knowledge about teaching strategies, assessment, and students' learning with teachers in the United States. On the basis of this understanding of science education and some experience teaching science in Korea and in the United States, the researcher started her doctoral program and some projects through collaboration with science educators and teachers in K-12.

For the last several years, the researcher, as a participant or educator, has attended various projects, conferences, and workshops and she found that science teachers, from preservice to experienced teachers, were most interested in teaching scientific inquiry in the classroom. Science teachers are eager about learning how to teach science as inquiry, but they are not confident implementing it in the real context of classroom. The main reason why teachers are uncomfortable implementing scientific inquiry activities is because of uncertainty about the definition of scientific inquiry and the purpose of using it. Through communication with teachers and science educators, as well as from reading prior research studies, the researcher has developed knowledge about scientific inquiry in the classroom context, such as its success, failure, and implementation by teachers or researchers.

Most experience in interacting with science teachers and educators and studying about scientific inquiry led the researcher to conclude that the failure of scientific inquiry in the classroom is due to the absence of opportunities for students' scientific argumentation. Without opportunities for scientific argumentation developed by students, scientific inquiry can be considered only a hands-on activity. Scientific inquiry is not guaranteed by hand-on activities only (NRC, 1996, 2000). In addition to hands-on activities for experimental investigation, students need to have opportunities for minds-on activities that are often promoted by student discussion about science activities.

The study of scientific argumentation allowed the researcher to gain interest in learners' cognitive reasoning in the psychology field. The studies of Deanna Kuhn became the main studies for the researcher to define the term "scientific thinking" as a reasoning process. Kuhn (1989a, 1989b, 1992, 1993) defined that scientific thinking is students' abilities to differentiate theory from evidence, coordinate them, and adjust one to the other. Students as young learners, however, do not have these reasoning skills needed to understand how scientific knowledge is constructed. Dunbar and Klahr (1989) also showed that young learners do not display the reasoning skills to use data as evidence from their experimentation to support their hypothesis inductively or deductively. The implication for education that emerges from these two studies is that we need to focus on teachers' roles of scaffolding to help students develop scientific reasoning skills through practice. Teachers' input, questions, and prompts are considered the most important factor in providing students with the opportunity to practice those reasoning skills. Previous studies, however, seemed only to describe student discourse as responses to teaching and did not take the next step to describe teaching behavior and teaching strategies that lead to these students' responses. So far, the researcher's knowledge of scientific argumentation has been built on theoretical background from the readings and from practical experiences gained through communication with science educators and science teachers during all kinds of workshops, conferences, and projects.

The experience of working with science teachers from K-12 and instructors at the college level provided the researcher with confidence in collecting data through observation. The researcher has been one of the research team members of OCEPT since 1999 and she has had training and practice using the OTOP (OCEPT-Teachers Observation Protocols) instrument to observe teachers teaching science. This observational skill was one way of constructing the reliability in collecting the data.

CHAPTER IV

RESULTS

Introduction

To facilitate the presentation of the varied and complex data from this investigation, this chapter is organized in four sections. The first section, *Educational Settings*, presents general background information about the participants and the school context as well as a description of the classroom and lessons. The second section, *Mr. Field's Understanding of Scientific Argumentation,* presents the teacher's knowledge about scientific argumentation and teaching it in the classroom; the information in this section is based on interviews with Mr. Field and answers the first research question in this study. The third section, *How Mr. Field Promotes Students' Scientific Argumentation,* provides his models of explicit teaching strategies, with a description of each strategy and how it is implemented in the classroom. The fourth section, *How Students' Scientific Argumentation Differs in Response to Mr. Field's Explicit Teaching Strategies*, analyzes the different kinds of student argumentation that occurred in Mr. Field's classroom.

Educational Settings

School and Classroom Context

The researcher worked with a science teacher, referred to here as Mr. Field, who teaches seventh-grade science at a public middle school in a coastal Northwestern city. That city has a population of 9960 and its major industries include fishing, wood products, and tourism. The middle school where Mr. Field works has 446 enrolled students from grades six to eight. The socioeconomic status (SES) based on the number of students receiving free or reduced-price lunch is 44% compared to the state average of 39%. Student ethnicity is 85% White and 15% other races, including Asian (2%), Hispanic (7%), American Indian (6%), and African American (1%). In the State Assessment, this middle school ranked above the state average in reading (73% to the state average of 64%) and writing (70% to the state average of 66%), but below average in math (52% to the state average of 57%).

The researcher observed two units of instruction that were taught to two different periods of seventh-grade students in the same classroom. There were 27 students in each classroom and 50% of them received free or reduced-price lunch, which is higher than the school's average of 44%. The two classes had average academic levels. The students sat at seven different tables in groups of four and there was a separate table for the researcher to observe from (Figure 10). Three groups, A, B, and C, shown above, consisted of students whose parents gave permission for their child to participate in this study.

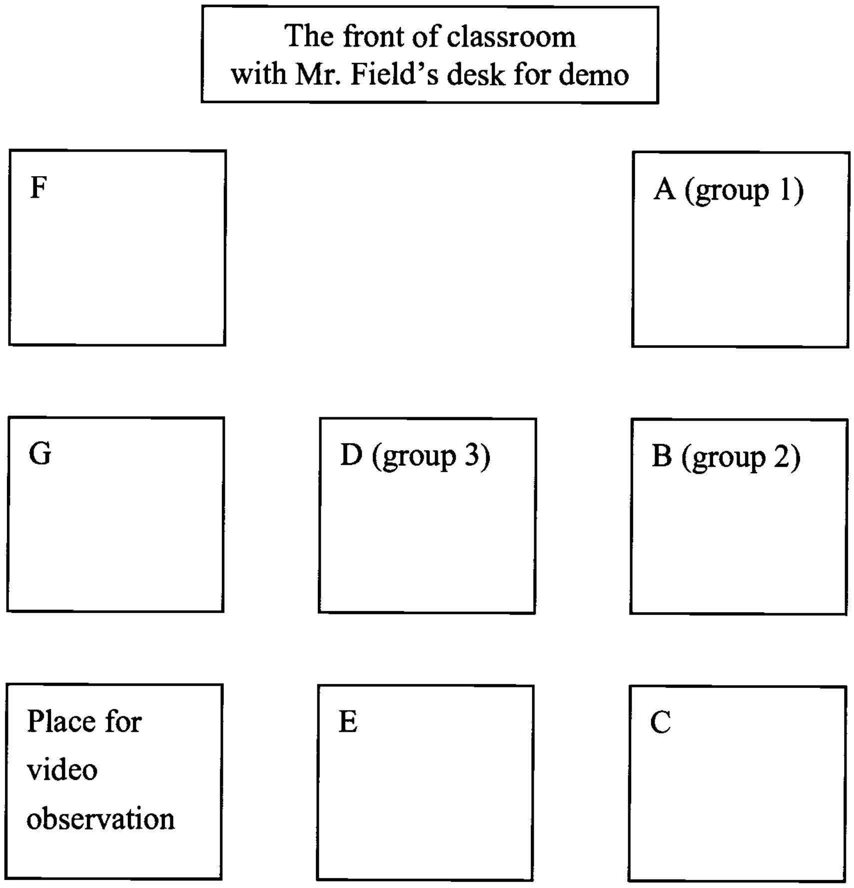


Figure 10: Mr. Field's classroom for the 3rd and 4th periods

<u>The Science Teacher (Mr. Field)</u>

Mr. Field is a seventh-grade science teacher, selected for this study out of nine participants. He has participated in the Oregon Department of Education's Scientific Inquiry Summer Institutes for the last three years as a member of the Oregon Science Teacher Leader Cadre representing his school district. He has taught seventh-grade physical science for thirty years and his highest degree is a master's degree in curriculum and instruction. Mr. Field also attends professional development programs regularly two or three times per year with the aims of (a) completing his school district's Science Curriculum Science Guide, (b) working with elementary and middle school teachers to implement inquiry-based learning opportunities, and (c) developing opportunities for teachers to use the Standard Based Science Tests to assess strengths and weaknesses of science content. Mr. Field is also the member of other professional groups, such as the National Science Teachers Association (NSTA) and Oregon Science Teachers Association (OSTA). When Mr. Field worked at the elementary level, his focus in a professional development program was mainly on how to assess students' learning and how to develop teaching mastery. Mr. Field now works at the middle school level and focuses on learning content as well as pedagogy skills.

Mr. Field believes that seventh-grade students need to start developing their appropriate reasoning skills by experiencing scientific inquiry. Mr. Field approaches scientific inquiry in a holistic way, with a focus on framing questions and analyzing and interpreting data. Mr. Field uses certain types of teaching strategies during the lessons in his unit, which will be described in detail.

Description of Students (Third and Fourth Periods)

The researcher selected two classes in a sequence for this study. There were 27 students in each class studied, Mr. Field's third and fourth periods, which were taught in their normal educational setting. The researcher selected two class blocks to increase validity in data collection. Mr. Field compared these two classes and mentioned that there was no difference in students' academic levels, ethnicity, or SES. Mr. Field and the researcher worked to assign students whose parents gave them permission to participate to the group tables that were observed most easily. In the third period class (Figure 11), twelve students at three tables for the first unit and seven students at two tables for the second unit were observed during the study.

Group #	Name	Role	Reading	Math	Birth date
1	Meagan ****	Tracker (**TR**)	2**	2**	6/07/92
	Ashley ***	Communicator (**COM**)			5/05/92
	Casey ***	Equipment Manager (**EM**)	2**	2**	9/05/91
	Harrison ***	Checker(**CHE**)			12/30/91
2	Austin ***	Communicator	2**	2**	5/05/92
	Katie ***	Checker	2**	2**	2/23/92
	Tessa ***	Tracker			7/21/92
	Mercedes ***	Equipment Manager			2/14/92
3	Jesus ***	Tracker		2**	3/16/92
	Krysta ***	Communicator	2**	2**	7/18/92
	Chey ***	Checker	2**	2**	5/21/91
	Mark ***	Equipment Manager			3/16/92

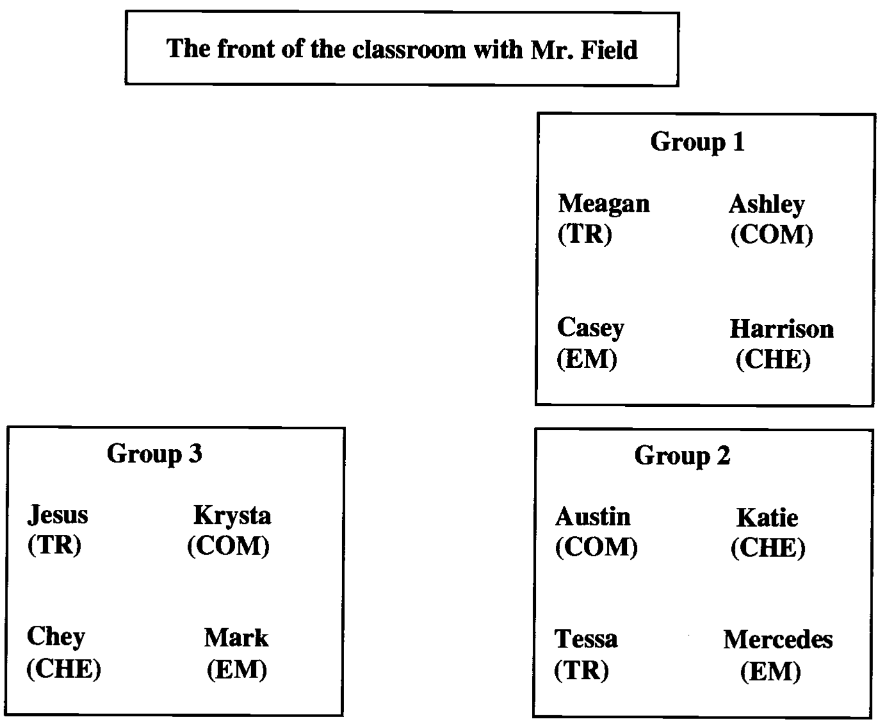


Figure 11: Example of students' information in the third period & its classroom arrangement (first to third weeks of class observation).
* indicates students' last names or numbers removed

In this period, there was one student in ESL (English as a Second Language) and one student on IEP (Individualized Educational Program) who had emotional disabilities. In the fourth period class, twelve students at three tables for the first unit and eight students at two tables for the second unit were observed. There was one student in ESL, two students on IEP, one student in TAG (Talented And Gifted), and one student with a behavioral problem. Only the selected groups in each block were observed through a video camera, but all students' voices were recorded during the lessons.

Mr. Field's Understanding of Scientific Argumentation

Mr. Field was selected based on his understanding of scientific argumentation and his explicit teaching strategies, as examined in an interview and a classroom observation that were used to select him out of nine initial participants. The criteria used to select Mr. Field for this investigation included (a) his knowledge of scientific argumentation as well as scientific inquiry as defined by Kuhn (1989) and Driver, Newton, and Osborne (2000); (b) evidence of his explicit strategies for encouraging students' scientific argumentation, such as using questions or prompts to encourage students to express their own ideas, captured through class observation; and (c) his current attendance of professional development programs with the purpose of developing and designing teaching strategies about scientific inquiry. This section describes Mr. Field's understanding of teaching and learning scientific argumentation as well as scientific inquiry, as collected under the interview protocols.

Definitions of Scientific Inquiry in His Classroom

Excerpts from interview transcripts are presented here with **highlighted** summary headings to guide the reader in constructing an understanding of Mr. Field's concept of inquiry teaching. Mr. Field defined scientific inquiry as giving students the opportunity to use creativity to design their own investigations to answer their own open-ended questions. The following excerpt displays Mr. Field's understanding about scientific inquiry.

> ***Designing the investigation to answer the question:*** *Originally scientific inquiry was designed to be an open-ended experience that kids could use their creativity to explore open-ended questions or even come up with an investigation on their own that they could investigate either in the classroom or at home and then bring in the work that they have done*

Mr. Field believes that it is important for students to initiate and design their own investigations based on questions that they have developed. He added that it is essential for teachers to teach inquiry in pieces first, and then to provide a framework as a guide for students to follow linearly. That is, students need to understand the basic inquiry skills first, such as differentiating dependent variables from independent, in order to design their investigation. The development of the ability to differentiate the dependent variables from the independent is easier in physical science than in other subject areas, such as life science or earth science.

> ***Students' abilities to differentiate independent from dependent variables as basic skills to do scientific inquiry:*** *lot of it depends – the interesting thing in inquiry when I was teaching physical science, where it is very easy to control the variables, you could do a lot of labs that were set up so that there was some creativity in the way they framed it, but it wasn't that hard to control variables. We did earth science and we did life science, and it is much harder to control the variables and the kids sometimes weren't as successful, especially in terms of analysis, because it was just so hard.*

At the seventh grade level, Mr. Field emphasized the practice of collecting data and transforming it into other representations, during a whole process of inquiry that was based on students' own questions.

> ***Self-designed inquiry guide with the emphasis of analyzing and interpreting data strategy****: I tended to teach the inquiry process in pieces. We might, as a class, develop a frame that we work under. Then I would give them a specific design that they had to follow, but it was up to them to determine how they were going to collect and show their data without getting any instruction from me. Then the analysis was very structured, hoping that they would use that as a model and learn how to do it when they were told to do it on their own.*

Mr. Field uses an *Inquiry Guideline* (Figure 12) for each lab activity and students follow the guideline during their investigation and while writing their lab report. Under the structured guideline for scientific inquiry, Mr. Field provides students with opportunities to reflect on each step of their scientific inquiry to see (a) how their research questions connect to the content that they are learning now, (b) how their data are appropriate to confirm their hypothesis or question, (c) how their conclusions emerge from their own collected data, and (d) how their conclusions connect directly to their own research questions.

- Report the results.
- Identify patterns.
- Talk about what you think happened and why.
- Look over your design and tell of anything that caused a problem
- Write a conclusion that tells:
    - What was the question and the claim
    - If what you thought would happen and how you know.
    - How the problems could be solved.
    - What is another experiment you would do with this equipment?

Figure 12: Self-designed guideline for scientific inquiry in Mr. Field's classroom

The Differentiation of Scientific Inquiry Activities from Hands-On Activities

Mr. Field differentiates scientific inquiry from hands-on activities in that scientific inquiry is the combination of procedural skills developed through hands-on activities and reasoning skills developed through discussion. Mr. Field believes that students need to use their reasoning abilities to perform and understand scientific inquiry, and they need practice using evidence to confirm or disconfirm their claims. To make this happen, Mr. Field implemented a new *Claim-Evidence Approach* that he learned through his professional development program. This approach will be discussed in more detail later in this chapter.

Mr. Field emphasized the development of background information before each lab activity, based on students' prior experience and knowledge as well as on information from the textbook. Mr. Field believes that this process of developing background information is essential in promoting students' reasoning skills necessary to carry out scientific inquiry activities. That is, Mr. Field defined reasoning skills as students' abilities to apply their knowledge or experience by framing questions and supporting their positions against opposing ones. To make scientific inquiry happen, Mr. Field also believes that students need to have an opportunity to practice developing background information and using it in their investigations.

> ***Scientific inquiry as reasoning skills:*** *The hardest thing is for them to put the designing of the investigation together with the analysis of the investigation. I don't know why it is so hard for kids to do that, but they really have a hard time with that.*
>
> ***Practice of developing background information and application for inquiry investigation:*** *What I do is I give the kids a claim that we have taken out of the text. Background information could be the hands-on activities we have done as well as worksheets, as well as assignments that we have read. Then they have to, in their design, tell me whether they agree or disagree with that claim*

> *and why. They have to state their evidence right there based on their background and information. Then I require, in their analysis, for them to go back and read the claim, read their evidence and then state whether or not if they have learned anything from the beginning of the investigation to the end. Do they still think that evidence is valid? Do they still think that claim is valid, and why? The "and why" part is where they will pull in their collection of data to prove or disprove what is going on.*

However, Mr. Field added that there are limitations for students at the seventh-grade level to design investigations that explore their own questions without a teacher's guidance, since the students have limited background knowledge in science content areas. In light of students' amount of scientific knowledge, Mr. Field believes that students at the high school level are ready to construct reasonable arguments that are valuable in understanding how scientific knowledge is constructed.

Explicit Functions for Scientific Argumentation

When Mr. Field was asked to differentiate scientific inquiry from hands-on activity, he mentioned that there must be more than procedural skills used during investigation. Describing students' abilities to perform scientific inquiry, Mr. Field stated that students must develop background information to support or refute their claims. For the purpose of implementing scientific argumentation in the classroom, Mr. Field employed certain types of models to provide students with opportunities to develop their argumentation skills: (a) the *Claim-Evidence Approach*, (b) communicative chances to express alternative ideas, and (c) opportunities to reflect on and reason through the process of science learning.

Mr. Field employed the *Claim-Evidence Approach,* a new teaching strategy that he learned through summer institute workshops on scientific inquiry two years ago. Mr. Field participated in a workshop where this teaching approach was introduced. It is a deductive method of teaching in which Mr. Field first provides a "Claim" from the textbook. With Mr. Field, the students develop background information for a lab activity. Students then develop their own questions and collect data. Students also must differentiate the evidence from the data and use the evidence to support their claim. Mr. Field believes that this approach, the *Claim-Evidence Approach*, connects the science content with students' lab activities, which he feels had been separated from one another. In other words, Mr. Field thought that he taught students scientific inquiry separately from science content learning before learning the *Claim-Evidence Approach*. The following excerpt from Mr. Field's interview explained the advantage of implementing the *Claim-Evidence Approach*.

> ***Advantage of using Claim-Evidence Approach**: I've gone ahead and given it a try. I understand what they are trying to do. They are trying to link the content to the inquiry in a harder and more specific fashion. I think that is good. What it has done for kids is it has tied the laboratory experience to the textbook experience. They are pulling it together more I believe that is true, and they tend to see, many times they don't see the link between the hands-on learning and the text learning. Even when we were studying it in the book and doing it, and not doing this very much, but when they are actually taking the piece of content that they have read in the text and putting it into the frame, it really linked it. They found that they had to go back to the text to understand the framing to do analysis. It is good. It is working a lot better than I initially thought. It is kind of fun.*

Mr. Field also emphasized giving students chances to communicate and share their different opinions. One example of these communicative chances included students doing lab activities in teams. With Mr. Field's input or questions, students are supposed to solve problems based on the background information they learned from the textbook. During this process, students need to develop the skills to differentiate evidence from data and to support their claims or questions. Mr. Field also stated that it is important for students to feel comfortable communicating their own ideas in making a guess or prediction while attempting to solve the problems in their groups.

Another teaching strategy Mr. Field uses in order to allow students to express their ideas freely is *Daily Science*. This strategy helps students develop background knowledge on the next lab activity or on content they were learning.

> ***Students' chance to express their alternative ideas***: *They have to get away from "there is always only one correct answer." We begin every class period with an open-ended question that they have to make their best guess at. They get to look at it and determine if their guess was correct and then change their guess to the correct answer. That builds more background knowledge, too. In this particular activity, to help them analyze, they knew where they were going and they knew what the purpose of it was. They realized, and it was structured in such a way that there were ten numbers. There were ten observations that they made. And there were ten hypotheses that they made and then their analysis had to blend those two together at each specific site. Then when they were done, they had to look for a pattern. Were we successful or not and why? What things works and what things didn't work?*

Mr. Field uses the *Daily Science* teaching strategy to give students an opportunity to express alternative ideas. Students develop arguments to predict what would happen and why it would happen. Students develop the abilities to manipulate and apply their prior knowledge to find new patterns, as well as to evaluate their new knowledge using certain criteria. Students also evaluate their investigation to see if it was successful or not. If not, students discuss the limitation of their investigations.

For more effective communicative opportunities, Mr. Field uses the *Johns Hopkins Learning Model (JHLM)* for group work, assigning a different role to each student in a team. The students practice four different roles in working as a team: (a) a communicator who initiates the discussion, (b) a tracker who records the data, (c) a checker who follows the appropriate procedures for the inquiry activity, and (d) an equipment manager who collects the materials needed for the activity.

> ***The different roles in groups for students' learning:*** *Each person in the cooperative team has a job. There is a communicator. That is the only person on the team that can talk for the group, and that person is the peacemaker in the group – tries to make everybody get along. There is a checker whose job is to make sure that they are following the procedures. There is the tracker that writes down the team's data, and there is the equipment manager. Every time I put them into a new team, they have to have a different job. Throughout the year they are going to have all four of those roles.*

Students come to know that there are alternative opinions about the same observation or experiment, and they learn how to negotiate their different opinions in order to achieve a consensus.

Mr. Field provided opportunities for students to reflect on the process of learning science as inquiry. One opportunity for reflection comes from Mr. Field's implementation of the *Inquiry Guideline* (Figure 12) during students' lab activities and before students write lab reports. The *Inquiry Guideline* describes the steps of scientific inquiry. Students can reflect on their data or results and see how they connect to the content they are learning.

In addition to the *Inquiry Guideline*, Mr. Field provided another opportunity for students to think about the quality of knowledge that is needed to develop new scientific knowledge. To accomplish this, Mr. Field explained and discussed *Bloom's Taxonomy* with students. Mr. Field discussed what level of thinking skills his students require to perform and understand scientific inquiry at the seventh-grade level, with the hope that students could advance from applying those skills conceptually (recalling) to procedurally (applying) in a new situation. Finally, Mr. Field also explained what a scoring guide is and how he uses it in assessing students' lab report writing. For example, Mr. Field explained students the difference between a score of 3 or 4 in the part of *collecting and interpreting the data* section of the scoring guide, in that kind of evidence from data could be used better to support their results (Appendix G).

Summary: Mr. Field's Understanding of Scientific Argumentation

Basically, Mr. Field believes that students at the seventh-grade level can develop the reasoning skills needed to perform and understand scientific inquiry by practicing using reasoning with a teacher's guidance and discipline. To meet this goal, Mr. Field uses some explicit teaching strategies to provide students with opportunities to demonstrate and promote their reasoning skills based on scientific investigation.

> ***Students' abilities to be scientifically literate through practices of teacher's role of scaffolding****: Teaching, it is in such flux that I could have taught that to last year's group, which was a very mature, non-social group that was academically oriented and they just did outstanding stuff. I would have gone through the same protocols this year, and this year's class is extremely social, very low academic, almost across the board. A bunch of them just aren't getting it. I am not talking at a level that they understand or they are just not mature enough to even care about it. There is only so much you can do, and in some respects you are just going to have to – the way I see it, I am exposing them to the format. I am showing them how to do it. I am giving them an opportunity to demonstrate the skills that they have at this point. I am documenting that in the portfolio. It is up to them to grow to the point where they can*

Mr. Field stated that his teaching is successful when students can demonstrate their skills in collecting many different types of data and create representations of that data in another form (i.e., graph). Mr. Field believes that students have the ability to develop their own questions, but they do not yet have the ability to collect evidence to support their claims using the appropriate representation of data. Mr. Field provides students with opportunities to see what scientists do by visiting their research sites. Mr. Field believes that scientific inquiry done by students at school cannot be the same as inquiry done by scientists at research sites. However, it is possible for students to develop reasoning as well as procedural skills through the practice of doing scientific inquiry activities.

> ***Hardship of school scientific inquiry to be authentic:*** *I guess what I learned from that was that a collection of data is many times much more difficult than you find trying to teach kids how to do it in a classroom. [Omitted] They are very, very hesitant to make any broad statement that this is true or that is true. I didn't realize what small steps they really go in. Professionally it would just be the kiss of death to say something is true and not be able to really prove it. In the science classroom, as I have heard before from parents, we are really not looking for all of our kids to be little scientists. What we are really looking for, in my mind and this is my personal philosophy, is if they use the scientific method to solve problems that occur in their life, it will make it possible for them to be more successful and not make a lot of mistakes*

Mr. Field believes that students at this age (12 or 13 years old) are developmentally beginning to understand the mechanism of cause-and-effect thinking. Mr. Field responses that it is his role to scaffold lessons at this point to allow students to practice scientific thinking and argumentation, in order to understand how scientific knowledge is constructed.

How Mr. Field Promotes Students' Scientific Argumentation

Mr. Field's explicit teaching strategies for developing students' scientific argumentation emerged during sixty hours of class observations. This section consists of three parts: (a) a description of Mr. Field's instructional framework for each unit and each lesson, (b) a description of each of Mr. Field's teaching strategies to promote scientific argumentation, and (c) a general description of Mr. Field's teaching on scientific argumentation based on classroom observations.

Mr. Field's Instructional Framework

This section describes the content taught by Mr. Field for this study, the framework he used for teaching the unit, and the framework he used for teaching each lesson. Data were collected from class observations, the lesson plans for the units, and conversations with Mr. Field before or after class observations.

Macro Framework for Units

Mr. Field taught two units from the textbook, *Motion, Forces, and Energy* (Kahan, 2000), using the content of Newton's three laws of motion: (a) first, that an object at rest will remain at rest and an object that is moving at a constant speed will continue moving at a constant speed unless acted upon by an unbalanced force; (b) second, that force, mass, and acceleration are related, in that the net force on an object is equal to the product of its acceleration and its mass; and (c) third, that if one object exerts a force on another object, the second object will exert a force of equal strength in the opposite direction on the first object. Mr. Field's first unit dealt with Newton's first law in the *Rocket Balloon Activity;* the second unit addressed Newton's third law in the *Marble Activity* designed by Mr. Field. Mr. Field assigned new groups of four students for the lab activities using the *Johns Hopkins Learning Model* (Figure 13).

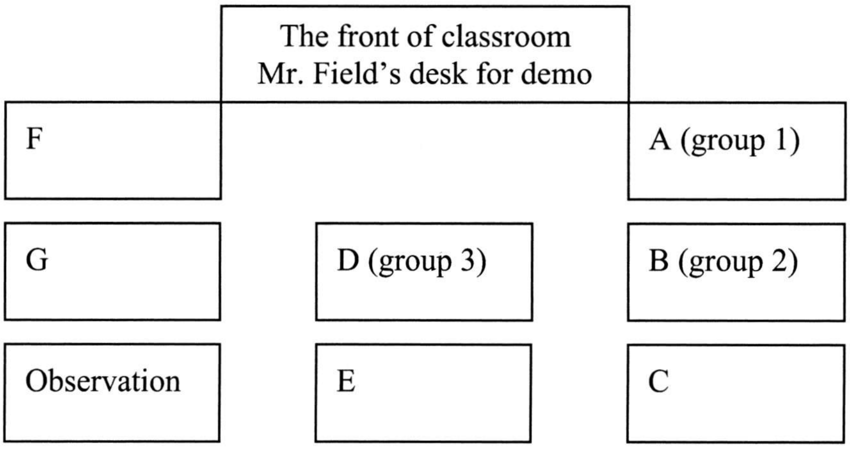


Figure 13: Mr. Field's classroom setting

The researcher visited for class observations that lasted for nine weeks, including preparation time so that students felt comfortable with the researcher's presence (Figure 14).

Monday	Tuesday	Wednesday	Thursday	Friday
			9/15	9/16
9/20	9/21	9/22	9/23	9/24
9/27	9/28	9/29	9/30	10/1
10/4	10/5	10/6	10/7	10/8
10/11	10/12	10/13	10/14	10/15
10/18	10/19	10/20	10/21	10/22
10/25	10/26	10/27	10/28	10/29
11/1	11/2	11/3	11/4	11/5
11/8	11/9	11/10	11/11	11/12

Gray Cells: Preparation time before observation
Black Cells: No school during observation
Dark Gray Cells: Testing Video and Audio Equipment
White Cells: Class Observations

Figure 14: Class Observation Schedules

The classes spent three weeks on each unit, both following the same macro-framework (Figure 15). Mr. Field used one or two lesson periods to test and assign students into new groups.

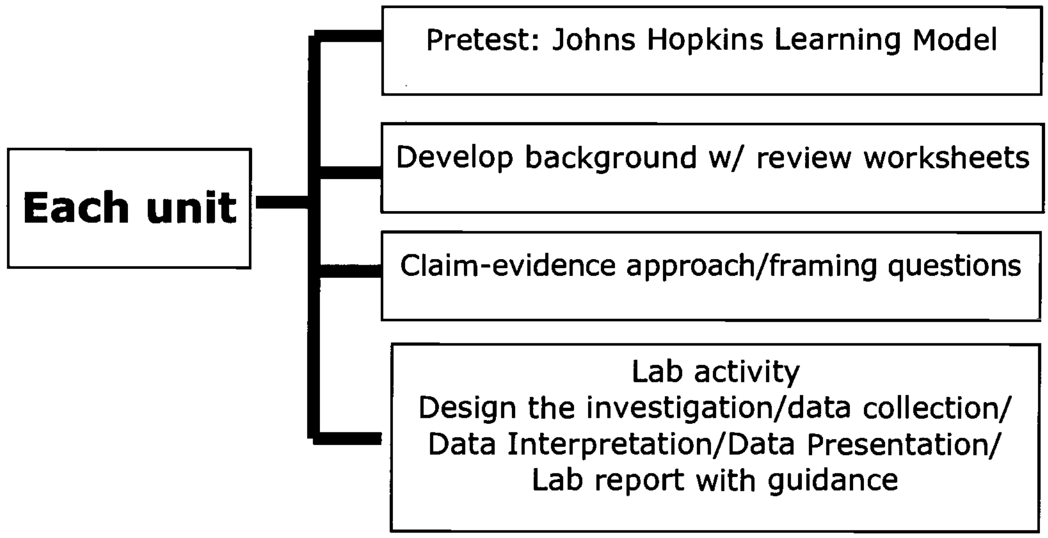


Figure 15: The macro-framework for Mr. Field's unit instruction

Second, Mr. Field used the textbook to develop the students' basic background knowledge about the content (Newton's laws) that they were learning. While Mr. Field and his students developed background information, students worked on one or two worksheets per section of the unit to review the content, then turned them in after scoring. Mr. Field spent five or six lessons on this background instruction.

Third, Mr. Field provided one general principle from the textbook (Newton's first law for the first unit and Newton's third law for the second unit) and students developed claims to be investigated in their own words. Students then framed questions or hypotheses to explore based on their own claims. At this point, Mr. Field emphasized the steps of scientific inquiry explicitly using *Bloom's Taxonomy* or the *Inquiry Guideline* as assessment tools to reflect on students' understanding of science as inquiry. Using *Bloom's Taxonomy,* Mr. Field explained what kind of knowledge is higher quality or lower quality. He also stated what kind of knowledge he expected from students at their age level. Using the *Inquiry Guideline,* Mr. Field explained how to frame questions, how to design an investigation, and how to analyze and interpret data. A more comprehensive description of these models will be provided later in this chapter.

Fourth, Mr. Field demonstrated a simple activity to help students design their investigation in groups. Students were supposed to find the dependent and independent variables needed to test their questions, then collect data and analyze their data using bar graphs (*Rocket Balloon*) or manipulations (*Marble Activity*). At this point, Mr. Field provided the *Inquiry Guideline* on the board, so that students could follow up their activity by reflecting on their experimentation while writing up their lab reports. Students wrote their hypotheses, their predictions explaining what would happen and why, and their claims on the first page of the lab report. Students did experiments to collect the data in groups, then analyzed the data using bar graphs or drawings. Finally, students wrote their results and conclusions following the *Inquiry Guideline* and turned them in.

Micro Framework for Lessons

A micro framework divides Mr. Field's lesson structure into three phases: *Opener, middle,* and *closure* (Figure 16). Mr. Field designed the first and last phases to introduce student opportunities to express alternative ideas and to develop extended scientific knowledge.

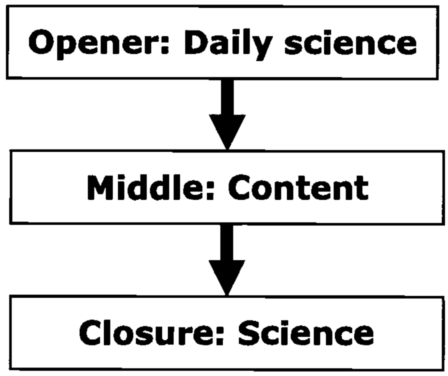


Figure 16: Micro framework for instruction in each lesson

Mr. Field used five or ten minutes at the beginning of the lesson as the opener phase. Mr. Field displayed one problem to explore on the overhead projector, and students solved it individually, writing their answers in their notebooks. This phase of instruction is called *Daily Science*. The problems given during *Daily Science* utilized physical science content as well as content on scientific inquiry and students were required to design an investigation or to find errors in some experiments. *Daily Science* occurred almost every day and Mr. Field checked the students' answers on every fifth day in general. Students discussed their own answers to each problem in a whole class discussion and turned their answers in after scoring.

Mr. Field spent 35 to 40 minutes delivering the main science content to students in the middle phase of the micro framework. The middle phase of instruction included (a) students' reading the textbook to develop their background knowledge before activities, (b) students' lab activities, and (c) Mr. Field's demonstration of the *Inquiry Guideline*, motivating students to reflect on their own investigation.

Mr. Field's professional development has included work in reading comprehension. His approach is consistent with recent research on teaching reading comprehension and the development of higher order thinking skills (Dole, Duffy, Roehler, & Pearson, 1991; Cook & Mayer, 1988). Some lessons during this reading phase included interaction between Mr. Field and his students. Mr. Field guided the students to help them understand the text's structure and main ideas and anticipate how the material related to the forthcoming lab activity.

During the second part of the content phase of instruction, Mr. Field gave students opportunities to design their own investigation. Students developed their own claims based on their readings from the textbook, and they used new scientific terms from the textbook in framing their claims. Students developed the procedural abilities to differentiate the independent variables from the dependent and to collect data through experiments. Mr. Field used demonstrations of simple experiments to encourage students to think of all the variables, dependent or independent, in designing their investigation (such as in the *Rocket Balloon Activity* or *Marble Activity*). For example, students discussed what variables could make the balloon stay longer in the air by pushing it after observing Mr. Field's demonstration, in which he pushed the balloon with the use of straw nozzle at the end of the balloon.

Third, students discussed the limitations of their experiments under Mr. Field's *Inquiry Guideline*. Mr. Field and his students discussed how to design their experiments scientifically to produce better results. In addition to this instruction, Mr. Field often created an authentic inquiry environment (Crawford, 2000), when he posed conflicting theories with which students develop the more extended arguments. Other lessons included students collecting data and interpreting their data in bar graphs or manipulations, lectures by Mr. Field, or students working on worksheets to review the content after each section.

Mr. Field spent the last five to ten minutes in the *closure* phase by providing time for students to discuss an issue. Mr. Field picked one issue from the science section of a state newspaper, *The Oregonian.* Through discussion of the current science issue, Mr. Field provided students with the opportunity to develop extended knowledge and the ability to read maps with scientific symbols. This instruction was called *Wednesday's Oregonian,* and was supposed to occur every Wednesday. However, there were only three instances of *Wednesday's Oregonian* during the classroom observations. The purpose of implementing *Wednesday's Oregonian* was to provide students with the opportunity to extend their current knowledge in the science field, which students might use in the future.

Mr. Field's Teaching Strategies

Figure 17 displays Mr. Field's explicit teaching strategies with the name of each instructional strategy and a description of its implementation in the classroom.

Teacher Actions	**Framework**	**Classroom Observations**
Develop ideas for open-ended question Differentiate dependent from independent variables	Daily Science	Mr. Field provided chances for students to express their different ideas every day in the beginning of the lesson. The content of Daily Science included subject matter to ask the conceptual knowledge and scientific inquiry to assess students' procedural skills. Students were given open-ended questions and wrote those answers to turn them in. Mr. Field collected Daily Science in every other 4 days. This took place as a whole class discussion.
Develop the claim and hypothesis	Claim-Evidence Approach	Students were given chances to develop their own claims and hypotheses based on

Predict, Observe, and Explain Provide two competing issues Construct argument (warrant)		general principles from the textbook. Students predicted the results to explain what would happen and why it would happen. Students developed their background information with Mr. Field through reading and discussing some topics related to the content.
Reflect on investigation as a holistic way Find the pattern from the data Find limitation in experimentation	Explicit Reflective Assessment (Inquiry Guideline)	Mr. Field emphasized students' opportunity to reflect on what they have done in their experiments, such as if their data gave support to answer the questions, if their conclusions were based on their collected data, and if their claims or hypotheses reflected on their content. Mr. Field used the self-designed Inquiry Guideline for this purpose.
Assign students' roles in groups	Johns Hopkins Learning Model	Mr. Field used this model to assign students into new groups with specific students' roles in each. Mr. Field thought that students' learning in groups is essential for their learning science as inquiry.
Discuss the current scientific issue	Wednesday's Oregonian	Mr. Field discussed the current scientific topic from the local newspaper with the emphasis on students' skills of interpreting scientific symbols and gaining extended knowledge. This whole class discussion was supposed to take place every Wednesday.
Differentiate evidence from data	Scoring Guide	Mr. Field discussed Oregon Scoring Guide with students so that they could understand how their lab reports are assessed based on what criteria. Mr. Field believed that it is essential for students to know this point before their writing.
Differentiate higher order thinking from lower	Bloom's Taxonomy	Mr. Field discussed Bloom's Taxonomy so that students could understand what is higher-order thinking and lower thinking. Mr. Field explained his expectation of their thinking level at this grade.

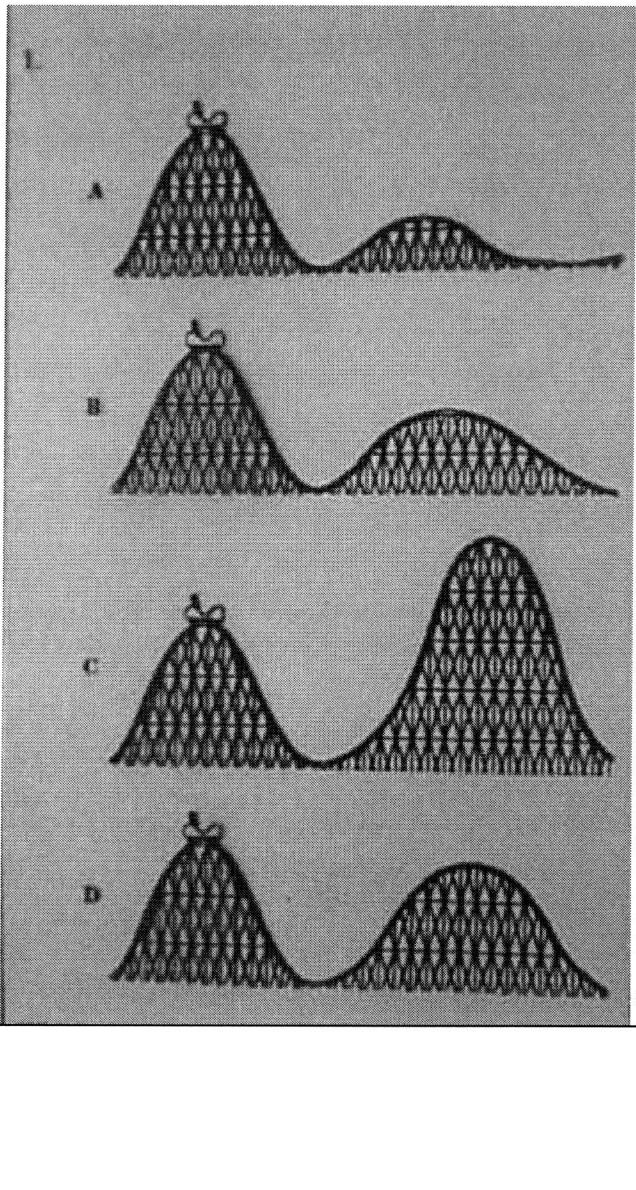
Figure 17: Mr. Field's Explicit Teaching Strategies for Scientific Argumentation

In the following sections, each teaching strategy will be explained with examples of how Mr. Field used it to provide students with opportunities to develop scientific argumentation skills.

Daily Science (DS)

Mr. Field implemented DS every day from Monday to Thursday. DS consisted of open-ended questions about the content they were covering (physical science) or about scientific inquiry skills needed to design an investigation. Students wrote down answers in their notebooks for each question. Students had the chance to talk about and share their ideas before writing the answer down in their notebooks. On the fifth day, Friday, Mr. Field discussed all four of the week's open-ended questions with the students as a whole class discussion. Mr. Field discussed all four problems with the class and students scored their answers to be turned in. During the course of this study, there were 19 problems given by Mr. Field. Figure 19 includes these open-ended questions covering two content areas, physical science and scientific inquiry.

Date	Daily Science
9/21/04	Discuss the difference and similarity between the work of scientists and historians. The source of energy
9/22/04	List of three types of pollution and one cause of each type (Pollution→ water, and what?)
DS 3	Label each statement as True or False 1. sound travels fastest in a liquid (F) 2. Sound energy that passes through a solid is said to be reflected (F) 3. Sound is made when matter vibrates (T)
10/04/2004 DS 4	What things are needed to make a closed circuit of electricity? Draw a simple diagram to explain your answer.
10/06/2004	Checking the Daily Science
10/07/04	Match the terms that describe wave motion with the correct meanings. Wavelength, amplitude, frequency. Amount of energy in a wave, distance between points on a wave, # of waves produced per second.
10/11/04	Rearrange the following according to how fast sound will travel through them. Liquid solid gas: Slower → faster
10/12/04	Two types of waves; sound and water. How are these two types of waves alike? How are they different?
10/13/04	Science instruments 1. separate light into colors 2. bend light 3. enlarges tiny organisms 4. used to view the stars

10/14/04	Check the answers of Daily Science
10/15/04	**No Daily Science**
10/18/04 DS5	How would you design an experiment to see which of 3 golf balls travels the greatest distance when hit?
10/19/04	A scientist wants to see which of 2 bean plants grows tallest. What's wrong with this experiment? Two different plants are placed in identical pots of soil, watered the same every day and given the same fertilizer. One is put under a grow lamp and the other put in the Sunlight.
10/20/04	Make a list of different forms of Energy in your classroom.
10/25/04	Design an experiment to see who's the fastest girl and boy in the class.
10/26/04	Check the answers of Daily Science
10/27/04	Design an experiment to see which object a magnet attracts.
10/28/04	A scientist thinks that it is easier to move an object using a wheel and axle than dragging it. How could he/she test this theory?
11/02/04	List three different things at room temperature under different states.
11/03/04	Energy is the ability to do work. How do kinetic and potential energy differ?
11/05/04	**NO Daily Science**
11/08/04	**NO Daily Science**
11/09/04	Which roller coaster will not have enough kinetic energy at the bottom of the first hill to carry the car over the second hill? 

11/10/04	A small ball is dropped down one end of a pipe. When air is blown in from the opposite end, the ball stops in the pipe. Which is a probable explanation? (1) The pipe fills with air which will keep anything from falling through it. (2) Gravity's pull is less inside the pipe than outside the pipe (3) The ball is made of very lightweight plastic. (4) The force of the air on the ball balances the pull of gravity
11/12/04	Which of these uses the force of gravity to make it move? (1) A sailboat moving across a lake (2) A car making a right turn (3) A snow sled going downhill (4) A bicycle rolling to a stop

Figure 18: Daily Science Problems during this study

Next, three examples of students' chances to develop argumentation during *Daily Science* will be discussed. The first two examples involved physical science content. These examples (Figures 19 and 20) revealed how Mr. Field interacted with his students in both linear and circular ways. The first example (Figure 19) showed linear interaction consisting of Mr. Field's questions, students' one-word answers, and Mr. Field's evaluation. The second example (Figure 20) shows the more extended interaction consisting of Mr. Field's question about what happened, students' answers, Mr. Field's elaboration asking why it happened, students' responses, and Mr. Field's extended explanations to complete students' ideas in a circular way. The third (Figure 21) involved scientific inquiry content.

In Figure 19, Mr. Field leads a discussion about how sound is transferred based on DS 3 (see Figure 18). Students provided examples from prior knowledge. Mr. Field then repeats their answers and provides a context for each response. The argumentation takes place as a linear way. Note that student examples come from modern technologies where sound is transmitted with radio waves and are not examples of sound propagating through materials. Mr. Field allows these examples to validate their thinking as they move to the next question.

TEACHER	STUDENT
What I would like you to do now is raise your hand and help us brainstorm some examples of sound being transferred.	
	On the phone.
On the phone is a good one. When the sound goes into the mouthpiece and out through the earpiece at the other side. Yes?	
	Radio?
The radio is a great one, too. We have sound with the person in the studio is talking into the microphone. Then you hear it at the speaker at home. Another one?	
	TV.
TV is kind of the same thing	
	Walkie-talkie?
Walkie-talkie is another good one. Anybody think of another one?	
	Microphone?
A microphone, that's right. Anytime you talk into a microphone or a megaphone, and then it comes out through a speaker, that is also a good example. Corbin?	
	Cell phone?
Telephone we have had already. OK, so let's take a look. You have basically come up with the same ones that my classes up to here have already brainstormed, too. So, good job. Yes?	

Figure 19: Linear argumentation during Daily Science

In the next example (Figure 20), Mr. Field asked further questions about students' ideas, which let them develop more extensive argumentation. **Highlighting** in bold in Figure 20 indicates Mr. Field's questions, his repetition of a student's idea, his elaboration, and his extended explanation making an interdisciplinary connection with the content of chemistry. In that instance, Mr. Field was relating how sound is transferred or reflected in different states of matter: solid, liquid, or gas.

Mr. Field first asked in what state the sound is fastest: *When it is passing through a phone, **what type of object is it?** Is it a liquid? Is it a gas? Is it a solid?* One student provided a one-word answer: *Solid.* Then, Mr. Field repeated the student's idea as a conclusion, ***Sound travels fastest through a solid,*** but provided another prompt, which might conflict with his conclusion, ***It doesn't seem like it should be that way, does it?*** To this prompt, another student responded that it is not the sound's speed but its intensity. Mr. Field evaluated, ***this one doesn't talk about intensity, it talks about speed,*** then provided an extended elaboration to explain how the sound transfers: ***The speed is pretty much generated by how closely packed together the molecules are. For some reason it moves very, very quickly when molecules are close together.*** The discussion between Mr. Field and his students were extended into the content of *Sound Reflection* from *Sound Transfer*. There appears to be some confusion in the dialogue concerning sound reflection and sound transfer. Mr. Field remains focused on making the point that density affects the transmission of sound. This argumentation occurred as a circular process of Mr. Field s' question, the student's simple response, Mr. Field's evaluation, student's response, Mr. Field's prompt, student's response, and Mr. Field's explanation.

TEACHER	STUDENT
Through a phone, okay. When it is passing through a phone, **what type of object is it?** Is it a liquid? Is it a gas? Is it a solid?	
	Solid
It is a solid. **Sound travels fastest through a solid.** That is a hard thing to understand. **It doesn't seem like it should be that way, does it**? OK? Yes?	
	Doesn't water increase the sound of it?
It could. **Since this one doesn't talk about intensity, it talks about speed**, OK. It could be that sound travels farthest in water, but it doesn't travel the fastest. **The speed is pretty much generated by how closely packed together the molecules are. For some reason it moves very, very quickly when molecules are close together**. For example, if you tap on a metal pipe, and somebody is a long ways away, you can hear the tapping very quickly. If you tapped on water, you probably wouldn't hear it. If you yelled in the air, you would never get there. Holly?	
	So it bounces back [in case of solid only]?
Yes. Sound energy that passes through a solid is said to be reflected, while if it passes through it, it is not being reflected, is it? Sound is made when matter vibrates. **It has to vibrate for there to be energy that moves through space.**	

Figure 20: Circular argumentation during Daily Science
(Highlighted in bold: Mr. Field's questions or prompts for students' opportunities for argumentation)

The next example of DS 5 (see Figure 18) focused on scientific inquiry skills. Again, the **Highlighting** in bold in Figure 21 indicates how Mr. Field scaffolded students to develop skills in argumentation. Throughout the discourse in Figure 21, Mr. Field's scaffolding for students to develop argumentation is marked with the letters A through F, to allow a detailed analysis of the argumentation strategies. Mr. Field and his students discussed how to design an experiment to investigate which of three different golf balls would travel the greatest distance. Students learned to differentiate independent variables from dependent variables in designing investigations.

Mr. Field first asked students what the independent variable is that they would deal with in designing an investigation about which of three golf balls travels the farthest (Figure 21-A). When students did not provide the answers that Mr. Field expected, he prompted them with another example of variables from an activity that students had carried out in the previous lesson (Figure 21-B). Students had already learned what the independent and dependent variables were in the *Rocket Balloon Activity*. Based on their prior knowledge from this activity, students could then identify the independent variable needed to design the new experiment by defining it in their own words (Figure 21-C). Mr. Field gave more detailed descriptions of the independent variable through concrete examples (Figure 21-D). Then, Mr. Field asked the students what the dependent variable in the new experiment was (Figure 21-E) and he again provided examples from the previous activity that students had already finished, *Rocket Balloon Activity* (Figure 21-F).

TEACHER	STUDENT
How would you design an experiment to see which of three golf balls travels the greatest distance when hit? Now, **when we were doing the rocket balloon lab there was a key word that we talked about that we were trying to get. It starts with the letter v. Does anybody remember what it is?** (A) JD?	
	Velocity?
Velocity, no, not the word.	
What is the things that we put on the x and y axis? What did we put there?	
	Variables
We put variables, things that change. Very good. That is what we are trying to do on this particular experiment. We have to figure out what are the variables. We have the independent and the dependent variables, right. Let's see if you can remember. **What was the independent variable in our rocket balloon lab?** (B) Raise your hand if you know. What was the thing you knew before you started the experiment?	
	The length of the balloon.
	Centimeters, length?
The length of the various different nozzles. What was the dependent variable? What did we learn as we went through the experiment?	
	How long it would have its flight?
The time of its flight, that's right. **Let's see if we can identify what the independent variable is in this experiment when you are trying to determine how far three golf balls will travel when they are hit.** (C) Who can tell me what the independent variable is? What thing do you know right now before you start the experiment? Drew?	
	How many golf balls.
How many golf balls you have. We know that the independent variables are the three different kinds of golf balls. I don't care if they are Nike, or **Top Flight or Titlist or they are Ben Hogan's or they are Callaway's**. (D) We are trying to determine which one of these balls goes the farthest. If you read a golf magazine, every other page is an ad about, "Buy our golf ball. It flies farther. It flies straighter. It has new technology." We have decided to find out if their claims are really true or not in this experiment	
	Three different golf balls, right?
Three different brands of golf ball, right. **What is our dependent variable? (E)** What are we trying to find out? JD?	
	How far they go.
How far they fly when hit.	
	In golf it makes a difference what club you use.
That is one of the things that we are going to talk about now. In just a moment, you are going to be given five minutes to talk in your group about all the different things that you have to control. **In our rocket balloon lab, what things did we try to control there? (F)**	

	Length of the nozzle.
The length of the nozzle was trying to be controlled, yes. Another thing?	
	How much air went into the balloon?
Very good. The balloon was supposed to be at 30 centimeters, wasn't it. We tried to control that variable. What other thing did we try to control?	
	[reference point]

Figure 21: Argumentation on how to differentiate the dependent from the independent variables during Daily Science
(**Highlighted in bold**: Mr. Field's questions or prompts for students' argumentation)

Overall, Mr. Field provided students with the opportunity to fill in the blanks of his argument structure. He also guided students in seeing the larger instructional focus on understanding controlled experiments. For example, Mr. Field connected the new content to the old one what students already learned and he gave concrete examples from the real world for the extended argumentation.

Mr. Field has collected *Daily Science* topics for the last ten years. Mr. Field uses *Daily Science* to (a) help students not feel threatened if their guesses are wrong, and (b) allow him to discover or discern students' prior knowledge and misconceptions, so as to help students develop new knowledge based on their prior experience.

> ***The purpose of implementing Daily Science:*** *The primary goal is to introduce them to content they are not familiar with, and to give them an opportunity to make hypotheses in a non-threatening manner, so they get used to making guesses. The other idea for them, it is a spiraling curriculum, and the idea is that I introduce them to an idea now and later in the school year they will have that same idea come back and hopefully they have built the background knowledge to make a more qualified hypothesis to a new question. It is a way to spark interest, develop interactions in their cooperative teams, share knowledge, maintain accurate records without losing them – another skill that they need to develop – give them a focus for science at the start of the period to help them to start thinking about science (Mr. Field's 2nd interview)*

Daily Science follows a general pattern of instruction: (a) Mr. Field provides one open-ended question, (b) he assesses students' prior knowledge by letting them sharing their ideas in groups or as a whole class, and then (c) students learn how to construct knowledge in the community setting. As an important step in understanding science as inquiry according to Mr. Field, students are exposed to others' points of view and come to understand how scientific knowledge is constructed through the use of communication to reach a consensus on the correct answers.

> ***The process of getting the knowledge in community:*** *Not only do they get to test their own answer, but they get to hear other kids' point of views of other answers that also can be correct. They begin to find out in science many times there is not only one answer to a question, but it is how you perceive it and what knowledge you have that you bring to the question before you start. From that, they get to have, which is another important things in science, a consensus of correct answers. That is also important to understanding of science (Mr. Field's 2nd Interview)*

Mr. Field described this understanding of science as a "process" of knowing rather than a "product" of knowing. Scientific knowledge is believed to be constructed in a community of scientists through the sharing of alternative ideas based on experiments and the reaching of a consensus based on those ideas.

<u>Claim-Evidence Approach (CLEA)</u>

The *Claim-Evidence Approach* (CLEA) is the main teaching strategy that Mr. Field employed for students' learning. This approach has two features. First, this approach is a deductive method for students to establish scientific claims based on their readings in the textbook or other sources. Second, this approach provides students with opportunities to develop evidence-based arguments that support or refute claims.

Mr. Field learned this approach at the Scientific Inquiry Summer Institute 2003, a professional development program. He had implemented this inquiry-based approach to science learning for one year at the time of this study. According to Mr. Field, the biggest benefit of using this approach is the connection between the content and lab activities. Mr. Field had not used a textbook to teach his seventh graders for the past ten years, because he felt that using a textbook separated lab activities from the content. Now, Mr. Field is confident that students can learn the content of the textbook through the lab activities, which are no longer separate.

Here is how Mr. Field implemented the *Claim-Evidence Approach* in his first teaching unit on Newton's first law during this study. First, Mr. Field used the textbook to develop background information about Newton's laws. The students learned new terms related to Newton's laws by reading the textbook. When Mr. Field encountered new terms that students needed to know, he paused for students to write them down in their notebooks. For each section of each chapter, Mr. Field gave a *Review and Reinforce* worksheet, and students checked the definitions or properties of new terms based on their readings. For example, students developed their understanding of new terms in the first unit (such as motion, reference point, speed, constant speed, average speed, velocity, acceleration, calculating or graphing acceleration, force, balanced or unbalanced force, and so on) to gain basic conceptual background information before the lab investigation.

Second, students develop their own claims using their own words based on the background information from the textbook (Kahan, 2000) about Newton's first law: *Newton's first law of motion states that an object at rest will remain at rest. And an object that is moving at constant speed will continue moving at constant speed unless acted upon by an unbalanced force* (p. 48). Along with having students develop their own claims, Mr. Field encouraged students to develop their own research questions or hypotheses and to design and carry out the experiments to find the answer to those questions. The following excerpt shows Mr. Field's understanding of how important it is for students to use their own voices and subjectivities in designing the investigation.

> *The first thing you are going to do, remember, you have to tell me what is going to happen. That means which one of these you are choosing. Why do you think it is going to happen? This is extremely important and the why you use these words. What and the why need to use those words. I want you to get busy now writing up your framing the investigation. It is going to tell me what you think is going to happen, which one of these is going to fly the longest, and why you think it is going to happen, using as many of these words as you can (Mr. Field's 2nd interview)*

The following excerpt (Figure 22) shows how Mr. Field provided students with the opportunity to develop their own claims to explore. Mr. Field's verbal instruction that emphasized the use of students' own voices in developing their claims is highlighted in bold. As seen in Figure 22, Mr. Field explained what CLEA is and how students develop a claim generally by saying, "*Inquiry means thinking creatively,*" or "*You start with an idea.*" Mr. Field also displayed his holistic understanding of the nature of scientific inquiry and the nature of science in terms of the subjectivity and creativity needed to develop claims by saying, "*[Claims] must be* *true... What if it is not true?"* and *"You put it in your own words that make sense to you."*

We are going to do something called the claims evidence approach to science.... **Inquiry means thinking creatively.** It used to be that you started at point A, hypothesis, and you went to point B, or F, actually, conclusion. You need to see science as a circle. **You start with an idea**. You do an investigation. As you are doing an investigation, new ideas occur to you, new things you'd like to learn. When you get to the end, you actually have five more things you might like to do. **The claim that I am going to lay on you comes from your textbook**. I'd like you to start now by looking at Newton's first law on page 48 and try to restate that. That is the claim. The book makes claims all the time and kids get in the habit of just willy-nilly walking along, "Well, the book says it is true. **It must be true." Oh, yeah. What if it is not true? Let's see if we can prove if it is true or not.** That is what the claim is. The claim I am giving you is Newton says this. See if you can take his words and put them in your own words.... **You put it in your own words that make sense to you.** What is Newton's first law when you read it? How does it make sense to you? Read it over. If you still don't get it, raise your hand, and I'll try to help you.

Figure 22: How to develop a claim (Oct 12^{th} OB)
Bold: Mr. Field's instruction giving students opportunities for argumentation)

Now, Mr. Field helped students develop their own claims by repeating definitions, giving concrete examples, and extending the knowledge needed for students to use in developing their own claims (Figure 23). Mr. Field's instruction that gave students the opportunity to develop argumentation is highlighted in bold in the following. Mr. Field contextualized and demonstrated one simple activity so that students were motivated to think of the variables and knowledge needed to develop their own claims by saying, *"If I put my rocket balloon here..."* and *"there is some energy added to it."*

Right, it says it won't stop unless there is force acting on it, right? Will it move when it starts? **If I put my rocket balloon here,** wherever I put it, if I set it here, is it going to move?
It never will move, will it, unless an equal and opposite force is placed on it. The first part of

Figure 23: Using the textbook to develop the claim of Newton's first law
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

This step of CLEA described in the Figure 22 and Figure 23 is called *Framing the Investigation.* Students developed their own claims based on the readings from the textbook about Newton's first law with the use of prior knowledge and background. Each student developed a claim to be tested derived from Newton's first law. Here are three examples of claims students developed. All students wrote down their own claims in their notebook. The first claim was developed by a student with a high academic level based on writing and reading scores, the second by a student with middle-level scores, and the third by a low-achieving student. There three examples showed the various quality of developing written argumentation depending on students' academic achieving levels.

> An object that is at rest will stay at rest unless acted upon by an unbalanced force. An object that is moving will keep moving unless stopped by a larger force (Hayley, 4RC) in 4th period, in Rocket balloon activity; grade assigned: **Complete**
>
> That every thing has a balanced it will stay in the balance until a force moves it or stops it (Stacey, 4RP) in 4th period, in Rocket balloon activity; grade assigned: **Partial**
>
> IF you see a ball on the table, it will not move until something moves it (Jesus, 3RL): in 3rd period, in Rocket balloon activity; grade assigned: **Limited**

Third, Mr. Field introduced the *Rocket Balloon Activity* lab and demonstrated a simple activity with concrete materials. Then, Mr. Field asked students to observe and discover the variables that make the balloon stay longest in the air, such as length of the nozzle (a straw) and the position of the balloon to shoot, reference point. Mr. Field distributed papers to the students with exact procedures and tables for data collection (Appendix H). Students in each group collected the same materials and data table sheets to carry out the lab activities, and then discovered which length made the rocket balloon stay in the air for the longest time. The length of time in the air was different for the different nozzle lengths and the students' observations were recorded in the data tables.

After his demonstration for students' observation, Mr. Field worked on helping students understand which variables would be dependent or independent in carrying out the rocket balloon activity. Figure 24 provides an example of how Mr. Field provided students with opportunities to differentiate independent from dependent variables while designing their investigation. The letters A through D in Figure 24 indicate how Mr. Field scaffolded students to develop argumentation. Again, key features of Mr. Field's verbal instruction are highlighted in bold.

As seen in Figure 24, Mr. Field asked what a variable was and students could not answer his question (A). Then, Mr. Field defined what a variable is to help students remember the term from their prior experience with other activities in which students had a chance to deal with different variables in designing an investigation (B). Mr. Field differentiated the independent from the dependent variable by defining each and appealing to an example (C and D) so that students could make some arguments that

Mr. Field expected. Mr. Field believed that the ability to differentiate the independent from the dependent variable in designing an investigation is essential to developing basic inquiry skills. After discovering the variables needed in the investigations, students had to collect and transform the data.

(A) No one has probably ever heard of something called a variable. **Have you heard of something called a variable?**

(B) **Something that changes is a variable**, that's right. Something that changes.. What you want to do in science is control the variables so that you are only testing for one thing. We are only testing for one thing. That is one of the big skills that we have to develop when you are making a lab up, is making sure that **you are just testing for one thing**. Has everybody written variable down?

(C) **This is called the independent variable, this bottom part**. The independent variables, and as we have seen already on this graph, we put time there. It is very, very important that you understand what an independent variable is. It is what you knew before you started. If you think about our two things that we have here, **time and distance**, the only one that we really knew that was going to go on a regular thing. The only thing **that would change on a regular basis was the minute**.

(D) The independent variable is the thing you knew before you started the experiment. We knew that **the time was going to go minute one, minute two, minute three, minute four. Did we have any idea how far this person would go?** No. We knew that we were going to have some distance on the other axis, but we **had no idea of how far she went unless we knew the time.** You can look at minute one and you can tell how far she went. If you look at minute two, you can tell how far she went. That is called the dependent variable. **The dependent variable – in other words, dependent like you are a dependent of your parents.** They are responsible for taking care of some of your needs. That way they can also declare you **on their income taxes as a dependent**. I am responsible for this person, so therefore I can claim them. The dependent variable depends on what minute we are talking about before we can tell what time we have. OK?

Figure 24: Mr. Field's teaching scientific inquiry skills of differentiating independent from dependent variables during *Designing the Investigation.*
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

Figure 25 shows some of Mr. Field's scaffolding to develop students' argumentation during the phase of data collection and transformation. Mr. Field's scaffolding specifically to develop students' argumentation is marked with the letters A through F within the discourse in Figure 25. Key features of Mr. Field's instruction are highlighted in bold in the discourse.

First, Mr. Field asked a question requesting a simple answer from students (A). Then, Mr. Field extended the content or skills to help students develop their reasoning by providing definitions of each mathematical axis and visual tools of drawings (B and C). Mr. Field went back to his original question, asking what the X and Y axis stood for in this activity about science content that they were covering (C and D). Finally, Mr. Field then could get the answers that he expected from students (D and E).

(A) A graph has two lines. **What** are those two lines identified as?
(B) As you can see, they are axis, aren't they? The runs that runs across – now do you have your sets of notes out in front of you? Get your set of notes out, please. [.....] On your notes, I want you to make **a vertical axis and a horizontal axis line**. If you don't know what I am talking about, look up here. **A line that runs up and down** is called the vertical axis. **The line that runs horizontally** is called the horizontal axis
(C) On this bottom line, over on the edge there I would like you to **write the x axis down**. If that is true, if that is the x axis, then the one on top here must be **the y axis**, right? Now you have your x and your y axis. That is just what we call it **in math**. That may not necessarily be what we call them **in science**. In science they have more particular names. If you were to look at the graphs on page 24, **what have we put on the x axis**?
(D) We have put time on the x axis. **What have we put on the y axis?** Yes?
(E) Distance. OK, there must be a reason why the authors of the book chose for that to happen. Could you tell me what is on the x axis, Preston?

Figure 25: Mr. Field's teaching using interdisciplinary connections to promote argumentation during *Designing the Investigation*.
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

In this example, Mr. Field scaffolded students to construct their knowledge based on the prior activity through re-defining, repeating, and extending the content from another source. This step of the CLEA instruction is *Design the Investigation* and is when students design the lab activity, also including smaller steps such as demonstrations for class observation, discovering dependent and independent variables needed to design the experiment, and collecting and transforming the data.

Fourth, Mr. Field encouraged students to analyze the data and find evidence to support their claims based on their patterns of data. If students could not find any pattern or any evidence that could refute their claims, they had another opportunity to developing an argument about why this happened and how this limitation could be overcome to make this experiment better. The last phase of CLEA, *Analyzing and Interpreting Results,* occurred at the end of the inquiry activity and was performed through students' writing rather than whole class discussion.

Figure 26 offers an example of how Mr. Field provided students with opportunities for argumentation as they wrapped up their activities. Mr. Field explained what students should report in their results, and implied that students need to use their own evidence (data) that they collected from their experiments to describe what happened in the results section of the lab report.

> The first thing you have to do is report the results. Now, report the results? That means that **you have to go back to your data and you have to tell me what happened**. That is what reports the results means. So go back to your data, and report your results (Oct 19, 2004; 4th period)

Figure 26: Report the conclusion from own collected data
(**Bold**: Mr. Field's instruction giving students' opportunities for argumentation)

The following excerpt (Figure 27) reveals more about how students use their data as evidence to support their claims and how they report the results through their writing during the phase of *Analyzing and Interpreting Results*. The letters A through F indicate how Mr. Field scaffolded students to develop argumentation in the discourse included in Figure 27. Mr. Field's instruction directed toward argumentation is highlighted in bold.

As outlined in Figure 27, Mr. Field emphasized the importance of using evidence that students collected themselves through experimentation in order to support their claims and hypotheses (A). Mr. Field also encouraged students to understand in what ways that evidence (data) supported their claims or did not, thereby developing students' argumentation (B). This step of CLEA is called *Analyzing and Interpreting Results* and is considered to be the most important stage in which students develop their reasoning skills by sharing ideas with peers in groups or with the teacher as a whole class. Mr. Field expected his students to understand what evidence they could use to support their own claims, how they could explain what happened using evidence, and how students could connect those results or conclusions to their own hypotheses or questions that were derived from their claims (C). Furthermore, Mr. Field provided opportunities for students to extend their thinking skills by describing the patterns of data to *generally explain* the mechanism of what happened (D) as well as reporting their exact evidence to be used to *justify* what happened (E). During this process, Mr. Field encouraged students to think of any factor which limited their experiment in terms of getting evidence (data) refuting their claims (F).

Don't you have the data written down in the data table? Let me try again. When you report results, this is where you **take information from your data (A)** and you put it down in your analysis. Show me that those numbers on your data are not just numbers, but you **really understand what they mean (B)**. So what do they mean? What were the results of this experiment? Don't tell me; write it on your paper. You have to look the data over and see if you can make sense out of it. Right underneath **Analysis and Interpreting Results (C)**, you can put is Number 1, if you want. [Omitted] Have you looked at your data table? What were the results? Look at the averages. [Omitted] I want you to **identify in any patterns you see and talk about what you think happened and why (D).** That is what we are looking for. Report **your results by talking about specific numbers on your data table (E).** What do you think the results will be? Can anyone give me an idea of **what you would be looking for off your data (F)** table? (Oct 19, 2004; 4th period)

Figure 27: Analyzing and Interpreting Results
(Bold: Mr. Field's instruction giving students opportunities for argumentation)

The following excerpt in Figure 28 shows how Mr. Field created practical opportunities for student argumentation in the domain-specific context of unit one, Newton's first law, with the *Rocket Balloon Activity*. Mr. Field checked the inquiry stages with an emphasis on reasoning skills and writing skills for the lab report. Mr. Field's scaffolding to help students develop argumentation is designated with the letters A through H in and with bold highlighting in Figure 28 below.

First, Mr. Field reminded students about how they could develop claims to explore as the starting point of inquiry activity (A). Students developed their claims, which could be their hypotheses or questions, from their readings about Newton's laws (B). To test their claims, students needed to select their exact evidence from their data that could justify their claims about what happened (C). Mr. Field provided one exact example of describing what would happen, providing a template for students to use for their writing (D). Mr. Field also explained in detail how students could use the background information that they learned during the first stage of CLEA to elaborate on and make their argument reasonable (E and F). Mr. Field then provided students with opportunities to share their ideas with others in groups, in order to help students understanding how scientific knowledge is constructed through interactions in a community (G and H).

> The first thing you are supposed to have is Newton's first law summarized in your own words. That was your claim, remember that? Remember, we went into the book and went into Newton's first law – anything at rest can stay at rest. **Anything in motion tends to stay in motion until acted upon by an equal and opposite force**. Remember that? **That is the claim that we are working on. (A)** We have the claims statement from Newton's first law, and read all of Chapter One. **We developed these vocabularies, and then I took you to Newton's first laws, and you wrote a claim (B).** I said this experiment was to determine whether or not Newton's claim was correct. **Then you were supposed to tell me which of the six different nozzle lengths you thought would work best (C).** We were going to try to tell . . . Remember, **after you have chosen the nozzle length, and you should have a statement that says, "I believe that when the nozzle is [blank] centimeters, the rocket will fly the longest."(D)** How many of you chose 10 centimeters for the length of your nozzle? No one in here chose 10. I will use that as an example, then. I am thinking it is going to be 10 centimeters. **Now I have to write a statement that has at least five of these words in it, and explains why I chose 10 centimeters (E).** Here is how I could write a sentence, and you think about it. Let's say I wanted to talk about it. **I think 10 centimeters will work best to overcome the force of gravity because. . . Use the reference point of the top of the desk. Energy from the balloon will cause it have some movement upwards towards the ceiling. With a short nozzle length, the mass of the balloon is less, so it will go a greater distance (F)** You see how we use those five words to explain what you thought would happen? Go ahead and take what you have written up right now, **trade it with your neighbor (G).** Let them read yours and **they can give you a little bit of input on whether you have done a good job or not (H).** (Oct 19, 04; 4th period)

Figure 28: Inquiry to develop reasoning skills through argumentation.
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

In summary, this new approach that Mr. Field started to implement one year before this study, the *Claim-Evidence Approach,* made Mr. Field feel confident that he is connecting the content from the textbook with the students' lab activities in the classroom. First, the CLEA started with students developing their background knowledge with the teacher's input regarding the specific content from the textbook. Then, Mr. Field interacted with students to help them develop their own claims to be tested within the content of unit. This early stage of CLEA is called *Framing the Investigation.*

Second, Mr. Field demonstrated simple experiments to motivate students to identify the variables for their experiments and to differentiate the independent from the dependent variables in designing their investigation. Then, Mr. Field guided students in carrying out investigations wholly (*Rocket Balloon Activity*) or partially (*Marble Activity*). At this stage, students collected the data and transformed them into other representations under Mr. Field's guidance. This middle stage is called *Designing the Investigation.*

Third, Mr. Field interacted with students to discuss how they would write the results, what evidence they would use, and how they would explain the mechanism of the phenomenon observed. At this point, Mr. Field emphasized the appropriate level of scientific reasoning skills for the students to understand how their inquiry activities were carried out, such as describing what happened, how it happened, and why it happened, thereby connecting all the stages of the inquiry lab activity. Mr. Field encouraged students to discuss extended skills and content in describing the pattern of data and the limitation of the experimentation. This last stage is called *Analyzing and Interpreting Results.*

Explicit Reflective Assessment

This strategy, *Explicit Reflective Assessment,* is connected to the CLEA. The CLEA is used in two ways: (a) one is as a teaching and learning approach in which the teacher delivers and students acquire content material in a deductive way, and (b) the other is as a tool to assess how well students understand the nature of scientific inquiry while learning the content, known as the *Inquiry Guideline.* In this section, the latter purpose of the CLEA is assessed. The following excerpt in Figure 29 describes how Mr. Field provided an opportunity for students to reflect on their understanding of scientific inquiry gained through argumentation. The letters A through G in Figure 29 link the transcript to the discussion below.

Mr. Field stated what students were expected to do in the first stage of scientific inquiry activities, by saying "*We talked about what was the claim statement*" (A). To help students develop their claims, Mr. Field gave the concrete example of Newton's first law, *"Anything at rest can stay at rest"* (B). Mr. Field then explained how an object thrown in the air would slow to a stop because of gravity, which also relates to Newton's first law. This was an opportunity for students to build a relationship between the event or observation, *"an object thrown in the air stopped to move,"* and the explanation, *"an equal and opposite force"* (C). Mr. Field extended the students' knowledge with merits to explain the mechanisms of how the event happened (D). To explain what happened, Mr. Field named the forces that were involved. Mr. Field prompted the students to use their knowledge or evidence to explain the mechanism of the phenomenon (E). He encouraged the students to think of "*what happened*" first as the conclusion or claims (F). Then, Mr. Field instructed students to use exact reasoning to support their claims (G). Here, Mr. Field emphasized exact evidence that was needed to support students' claims.

> Remember what we were talking about in **framing the investigation**. What did you think was going to happen in the rocket balloon lab? When we were doing the framing of the investigation, the first thing **we talked about what was the claim statement** (A). **Remember his law says anything at rest can stay at rest [forever]. If I put my binder on the table, I expect it to stay on the table and not move (B).** The second half of Newton's first law says something about anything in motion tends to stay in motion. **If I throw something, I expect it to fall back to earth because an equal and opposite force will slow it down and make it stop (C). Those forces would be gravity and friction, wouldn't they? (D)** Now **within the harder part was when we had to come up with the reasons why you thought that was going to happen (E). You began writing out an explanation of the reasons why you thought it would happen. First of all, remember what happened. Look at your "what" part that you wrote down – you cannot choose a couple of these (F).** Somebody, I think it might have been in here or 6th period said, "The best nozzle length is somewhere between 20 and 10 centimeters." You can't come up to fudge factor on your hypothesis. **You have to say specifically which length you think will be the right one. You are going to say 10 or 20 or 30 (G).** You can just say, "The best nozzle length is [blank] centimeters." That is the one. Then we had all of these words that we brainstormed. (Oct 13, 2004: 4th period)

Figure 29: Assessing how students develop their reasonable claims through argumentation
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

Figure 30 provides an example of students developing written argumentation skills during the *Rocket Balloon Activity.* Mr. Field gave concrete directions for writing the lab report, as scientists do after their research (A). Then, he gave an example of how to write a theoretical claim based on Newton's third law (B). On the basis of this sample report, Mr. Field provided feedback on the reasoning skills expected of students, along with the use of scientific terms and target principles (C). To help students understand appropriate scientific argumentation, Mr. Field provided an example that was not an acceptable scientific argument because it relied on slang and *ad hoc* reasoning (D). These two different examples, one from a specific scientific domain and one from the domain of everyday life, enabled students to understand what scientific argumentation was and how it could be demonstrated through their writing (E).

> **Let me give you a couple of ideas about how you could write a sentence that uses these words** (A). Let's say I chose 25 centimeters to be the best nozzle length. Now I have to say why. "I chose 25 centimeters because I think the energy from the balloon will cause its mass to go against the force of gravity in a movement up toward the ceiling, for the best distance." (B) Wow, that sentence had six words in it right there. **By using this vocabulary, you are demonstrating to me that you are thinking about this in the same way that we talked about it from our text book** (C). If you use other words, gosh, it sure would be cool if it did that, I think it would happen because my brother once shot me with a rubber band, so that is probably why it will happen that way (D). That is really not talking about what we have been learning in the textbook, is it? **What we are trying to do with this approach, this claims evidence approach, is work around the framework of what the text and the background is that we have been talking to you about** (E). Remember this is a rough draft that you have in front of you. (Oct 13, 2004: 4th period)

Figure 30: The development of written argumentation
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

Mr. Field provided the specific, self-designed *Inquiry Guideline* for written argumentation, through which students had an opportunity to demonstrate their scientific reasoning skills. Below are the five steps in the *Inquiry Guideline*:

1. *Report the results:* Students write their results with their collected data using new scientific terms that they learned while they acquired background information from the textbook.
2. *Identify patterns:* Students describe the patterns in the data, explaining the mechanism of the experiment in an extended way.
3. *Talk about what you think happened and why:* Students provide the mechanism of the experiment and justify with their concrete data.
4. *Look over your design and tell of anything that causes a problem:* Students have a chance to discuss limitations of their experiment that prevented them from getting the best results, and describe how to create a better experiment in a new context.
5. *Write a conclusion that tells:*
   A. *What was the question and the claim*
   B. *If what you thought would happened and how you know.*
   C. *How the problems could be solved.*
   D. *What is another experiment you would do with this equipment?*

Mr. Field instructed his students to use this five-step guideline for their writing and discussed all items of the guide with his students so that they could reflect on their reasoning skills through the process of writing.

The excerpt below (Figure 31) describes Mr. Field's instruction to guide students in developing their reasoning skills in the second step of the *Inquiry Guideline,* which is *Identify Patterns*. Highlighting and the letters A through D identify how Mr. Field scaffolded students to develop argumentation. Mr. Field encouraged students to find patterns in their data that could make their argument stronger (D). On the other hand, Mr. Field also told students to find patterns in the data that could make their argumentation weaker (C). Mr. Field's prompts provided students with an opportunity to develop extended arguments by using competing ideas (A and B).

I don't want you to just take your data table and just rewrite the numbers in your conclusion. You have to make some sense out of it. What do those numbers mean? Do they show you any patterns? **After you have looked for patterns, yes there is a pattern or no there isn't (A)** Yes, which nozzle went the longest? Which one? What is the pattern? Or you can say there is no pattern. **You have to tell me how you do know there is not a pattern (B).** Don't expect me to go, "Oh, I will look at the data, and oh, this is what they meant." **You have to tell me that there is not a pattern (C). You have to tell me what you mean if you do see a pattern (D).** Then why do you think you got the results you did in this experiment? (Oct 19, 2004; 4th period)

Figure 31: Find the pattern of the data
(**Bold**: Mr. Field's instruction giving students opportunities for argumentation)

There are more examples where Mr. Field instructed students to develop extended arguments when they discussed the limitations of the experiment, *Rocket Balloon Activity* (Figures 33, 34, 35, and 36). First, Mr. Field initiated the process by asking students to think of problems that prevented them from getting the best results (Figure 32). In order to do this, he used questions, prompts, and clues that enabled students to develop argumentation skills about limitations in general. To encourage students to express their own opinions about the limitations of designing the investigation in the *Rocket Balloon Activity*, Mr. Field gave concrete examples of limitations, such as popping balloons (Figure 33), the amount of tape (Figure 34), and the finger position when pushing the balloon (Figure 35). The concrete examples of limitations given by Mr. Field enabled students to discuss and develop their arguments in each case. At the end of this discussion of the experiment's limitations, Mr. Field added that students could design better experiments to get the best results by overcoming variables that limited their investigation.

Do you understand what I'm saying when I am talking about the design? How we did it. What were some problems that we had in the design making the results not really as good as they could be? (Oct 19, 2004, 4th period)

Figure 32: Discussion of the limitation of the experiment

We have no idea if these balloons are consistent in terms of how they push out air, do we? How many of you had a balloon pop during the course of the lab? Look around and you can see that one thing affected results in five of the seven groups. What else could there be, that would be something that would cause a problem? Look at the variable and what things changed that you could not really control, you had trouble controlling?

Figure 33: Discussion of the limitation of the *Rocket Balloon Activity*

The tape, how did the tape affect the results? Did everybody have exactly the same amount of tape that they used? Did I say, "Tear off 3 centimeters of tape and put it around the two straws?" I didn't do that. They might have used 2 centimeters and they might have used 5 centimeters, and the change in the mass might have affected our results? What else? There are a lot of things in this lab that we didn't control. Let's come up with some more. Different people? I want somebody else to come up with one. Give me something about the balloon. What could have been a factor about the balloon that might have caused a problem?

Figure 34: Tape as one of the limitations

Some person might have had it bigger when they started and another person might have let some *air seep out underneath their finger and thumb before they released it, right*? How about the taping of the balloon to the straw? Was there any variation between groups on that? Quite a bit, wasn't there? I didn't give you the balloon all made and said, "These are all the same." Any other variation? There are some other things.

Figure 35: The shooting force position as one of the limitations

Johns Hopkins Learning Model

Mr. Field implemented the *Johns Hopkins Learning Model* in two ways: (1) to assess students' prior knowledge before teaching a new concept; and (2) to assign students in new groups depending on their pretest scores. Each group included four different students' roles: Tracker (TR), Communicator (COM), Checker (CH), and Equipment Management (EM). Mr. Field used this model to assign students into new groups for the first unit of class observation in this study (Newton's first law), based on pretest scores.

Pretests included all different types of problems, such as multiple choice, short answer, and True or False questions. However, Mr. Field used students' academic levels to assign them into new groups without a pretest for the second unit that was observed (Newton's third law) due to a time issue. The reason Mr. Field implemented this model was to give students opportunities to grow socially and experience responsibility in their groups. Mr. Field believes that group work with different roles for students is an essential factor for students to practice and understand how scientific knowledge is constructed in a community. Summary headings are highlighted in bold in the following excerpts from Mr. Field's interviews.

> ***The importance of sharing alternative ideas in the community****: For the kids that know the information, for many of them it is the first time that they have had to share that information with someone that doesn't understand. They are learning compassion for other people that way, and learning that by using different approaches, they can help somebody else become more successful (2nd interview)*

Mr. Field believes that it is necessary for students to have different roles in groups to gain an understanding of how scientific knowledge is constructed by the community, such as the way scientists do at their research sites.

> ***The role of community in constructing knowledge:*** *In the real world, we rarely get to choose the people we work with. We have to develop the skills, the communication skills to understand the strengths of the people around us, and use them to help not only us be successful, but for them to be successful. For the higher achieving student, I am saying, "You need to learn these skills. You need to learn how to communicate. You need to learn how to share knowledge. If you can be successful at that, if you can teach somebody what you know, you know it better." That is how we go about it (2nd interview)*

Mr. Field implements the *Johns Hopkins Learning Model* all year round in every activity in his classes. He learned about this model for cooperative learning 15 years ago in a workshop. The next excerpt describes how Mr. Field emphasized the students' roles in carrying out the investigation by reminding them that their roles are needed to construct knowledge collaboratively (Figure 36). The relationship between these different assigned roles and the students' abilities to develop argumentation was not examined, but the communicator in each group initiated the discussion whenever needed. This excerpt describes the differences in procedural skills between the student roles during the experiment, rather than differences in reasoning skills while they were developing argumentation. Therefore, the data from this study did not show the relationship between students' abilities to develop argumentation and their different assigned roles in doing group work.

Who is the tracker here? Who is the checker? Remember the checker, it is your job to hear my directions and then be sure that your team does that. **The tracker, it is your job to stay on task and make sure all the data gets written down for your team.** If you mess up or if you lose it, your whole team suffers. You have to assume those responsibilities. Now if you would look at Number 1, on your procedures, **all the checkers and read it to yourself quietly**. [Omitted] **Equipment managers, you are going to get a pair of scissors, meter stick, some tape, a stopwatch and two straws.** All I want done right now is the two straws taped together. Equipment managers, come get what you need. [Omitted] **Communicators,** will you please tell me how long your straws are? (Oct 13, 2004: 4th period)

Figure 36: The assigned different roles in each group
(**Bold**: Students' roles in groups providing opportunity for argumentation)

Wednesday's Oregonian

On Wednesdays, at the end of the lesson, Mr. Field spent the last ten minutes on *Wednesday's Oregonian.* This did not happen every Wednesday due to lack of time. The reason for its implementation is to let students be aware of recent issues in the science field. For example, Mr. Field brought in the article "Total eclipse" from the *Oregonian* to assess what and how much students knew about eclipses. Additionally, Mr. Field provided students with some information on how to observe the moon eclipse that night, as extra credit homework. Here are scientific issues that Mr. Field selected from the local newspaper (Figure 37).

DATE	Content
10/27/04	Talk about the *Oregonian*, full eclipse, which will happen today
11/08/04	Read the Earth-week Map (Bird flu update, Drunken rampages, Earthquake)
11/12/04	Read the Earth-week Map (Antarctic hunger, Mediterranean swarms, Volcanoes)

Figure 37: Wednesday's *Oregonian* Newspaper Activity

First of all, Mr. Field emphasized the abilities to read and interpret the scientific symbols in the scientific section of the newspaper. The first issue examined was about gaining knowledge about the moon's partial or full eclipse, so Mr. Field discussed some skills and content needed for students to observe the eclipse that night. The other two issues were used to address students' abilities to reading and interpret scientific symbols displayed on the world map in the column "Earthweek." Here is an example of the "Earthweek" map including scientific symbols (Figure 38).

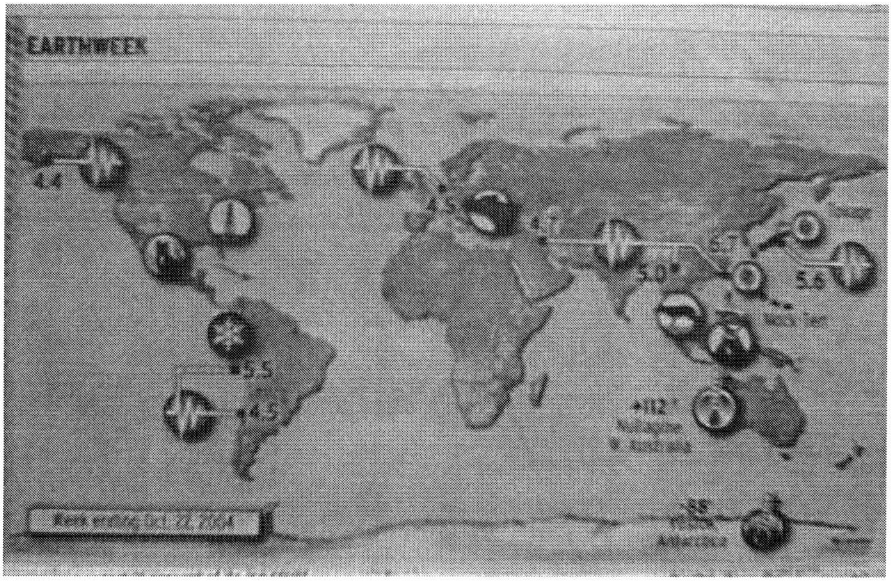


Figure 38: "Earthweek" with scientific symbols from newspaper

Mr. Field read the article from the newspaper first and then explained what the symbols meant and how students could interpret them, offering more description related to some of the symbols. For example, there were eight different symbols on the map, and Mr. Field chose one symbol explained that symbol by reading the article. One of the symbols indicated "Glaciers Shrinking" on South America. Mr. Field read the article from the newspaper, which included scientific knowledge on events happening now, what makes them happen, and how the events influence humans. The following is one excerpt about the "glacier" issue from the *Oregonian* (Figure 39).

> **Andean Glaciers Shrink**
> Ecuador's mountain glaciers are melting at an alarming rate because of **global warming,** threatening the country's future water suppliers, according to researchers. Ecuador's Meteorology institute and France's scientific research institute IRD said that the towering Cotopaxi Volcano has lost 31 percent of its ice cover between 1976 and 1997, and other such as El Altar could lose all of their snow pack during the next 10 to 20 years. Ecuador's capital, Quito, depends on snow-covered mountains for 80 percent of its water supply.

Figure 39: Earthweek from the *Oregonian* Newspaper (10/27/04)

After reading this article (see Figure 39), students asked questions if they had any, and Mr. Field provided more information related to those questions. However, students' questions were simple ones and Mr. Field spent most of the time lecturing while students were quietly listening. The following excerpt of the class discussion on the current issue from the newspaper showed how much information Mr. Field provided for students' content understanding (Figure 40). In Figure 40, Mr. Field's scaffolding that encouraged students to develop argumentation is highlighted and marked with the use of the letters A through I.

On the "Earthweek" map (see Figure 38), there was another symbol that indicated the lowest temperature in the world recorded for that week. First, Mr. Field concluded his remarks (D) on what patterns students could find on the map. Then, he provided the reason for why the extreme temperatures happened (B), explaining the mechanism of the phenomenon with more descriptions (A and C). These descriptions qualified the reason to make it stronger. Then, Mr. Field gave examples (E and F), which could be seen as the data used to justify the mechanism of the phenomenon. In addition, Mr. Field provided extended knowledge, which again qualified the reason (G and H).

Oregonian Newspaper Science Current Issue

I always start by taking a look at this highest and lowest temperature around the planet, because one of the things that we will be trying to identify is patterns. **As the earth goes around in its orbit (A), because the earth is tilted (B), the direct rays of the sun move north and south on the planet (C), and that affects temperatures (D).** Here our **highest temperature last week was right here in Saudi Arabia, at 116 degrees in the shade (E). The cold temperature was down in Antarctica at minus 101 degrees (F).** That is a tremendous difference in temperatures. When you have that, remember **when the air warms, it rises up, and when it cools it is drawn back in (G)** You can think **a little bit about all this heat coming up, and the air cooling, and causes a tremendous of air around the earth. At the same time, you have a ball spinning, and we can look at that a little more closely when we get to understand how weather patterns develop (H).** If you are not familiar with how cold this is, humans really aren't supposed to go outdoors, even if all of their body parts are covered. Below 60, if it is below 60 below zero, so this would be too dangerous.

There was kind of an interesting thing a couple of years ago. They **had the coldest temperature ever in the United States. They weren't talking about Alaska, they were talking about the lower 48, right up here in North Dakota. It was minus 56 degrees (I).** The weatherman went outside and he said, "A lot of people wonder just how cold this is." He had a thermos of hot coffee, and he said, "This is how cold it is." He took the lid off the thermos, poured himself a cup of hot coffee and it was steaming. He threw it up in the air and it froze and came down like snowflakes. It is that fast. It was that cold.

Figure 40: One example of a discussion about the current issue from the newspaper shows how much information Mr. Field provides for students' thinking skills
(**Bold**: Mr. Field's instruction offering students opportunities for argumentation)

Finally, Mr. Field gave more data, providing an opportunity for students to develop thinking skills, but he did not implement it as a whole class discussion. Even though this strategy was implemented through lectures rather than a whole class discussion, Mr. Field used this opportunity to broaden students' knowledge. The broader knowledge was said to be used as the basis on which students could develop new knowledge later. After each *Wednesday's Oregonian* discussion, students took a quiz based on Mr. Field's lectures about that issue.

Scoring Guide

At the end of the *Rocket Balloon Activity*, Mr. Field had a chance to talk about the *Scoring Guide* (Appendix G), Benchmark 3, to let students know how their lab reports would be assessed. For example, Mr. Field explained the difference between scores of 3 or 4 points on the designing an investigation part of the scoring guide. Mr. Field explained his expectations of students' abilities to do scientific inquiry and added how important it is to meet the needs of procedural skills at this level (seventh grade). The following excerpt shows Mr. Field's understandings of the importance of developing the required skills described on Benchmarks 3 of the *Scoring Guide* for middle school.

> Now, new piece of paper out, everyone. At the top of this page, write the following three words, analysis and interpreting results. Do you have that down on a piece of paper now – analysis and interpreting result. I am going to help lead you through this final part. Later in the school year, you will be expected to be able to do all of the skills that we have been working on with this lab – bringing up the investigation, designing the collecting and presenting of data, and the analysis and conclusion, on your own, without any help from anyone. That is what you have to do to pass the Benchmark 3 in 8th grade. By the end of your 8th grade year, you are expected to do this by yourself, without any help. I don't expect you to do it now. I am just trying to give

> you some experience, so that is it not all new to you. We are going to do a couple of these during the year. We are not going to do them all year long. A lot of experiments, you won't write this stuff out. We will just mess around and do the table, we talk about it, and we put it away (Oct 19, 04: 4th period)

Mr. Field emphasized the procedural skills for scientific inquiry in relation to the scoring guide, in order to promote students' reasoning skills through argumentation. Mr. Field understood that students' inability to develop argumentation is a result of undeveloped procedural skills and uncertain prior knowledge at this level.

Bloom's Taxonomy

Mr. Field described what the *Bloom's Taxonomy* is and why students need to know it during his lessons. He explained what kind of reasoning skills the *Bloom's Taxonomy* consists of—from basic recall to application—during the lesson. He added an explanation of what level of reasoning students need to achieve at the seventh-grade level. He gave a concrete example connected to the content that they were covering to help students understanding this taxonomy.

> On the Bloom's taxonomy of learning scales, there is basic recall. Our basic recall on this would be saying, what is the x axis, and you would look at the graph and you would say time. That is basic recall. That is not hard to do. We need to move up to the analysis side of Bloom's taxonomy, where you can actually try to understand what is going on from the pictures and put it in your own words. That is what you guys are butting up against right now. You need to get used to it, and you can move up over the top and understand this, because you all have the ability. When you become adults, no one is going to lay it out for you. Every single day you are going to come across situations that you are going to have to analyze and understand. We need to make that growth this year, get you ready to do those things (10/11/04 3rd group)

Mr. Field briefly explained this taxonomy during each activity, especially when students were about to transform their data into a new representation, i.e., bar graph or manipulation, and then interpret the data with the aim of supporting the claims. He also talked about this taxonomy when students provided only simple answers to encourage them to extend their knowledge and develop their reasoning skills to meet his needs during the lesson. *Bloom's Taxonomy* is the only aid that allows students to understand the different types of reasoning skills that they need to meet at their level, seventh grade.

General Teaching Profiles

A structured observational protocol, OTOP, was employed for the purpose of describing the pattern of Mr. Field's instruction. There are ten OTOP items describing effective teaching strategies envisioned by NSES (NRC, 1996, 2000). It is assumed in this study that the instruction delivered by Mr. Field must be described with the most frequently observed OTOP items: #4 (challenging ideas), #6 (conceptual thinking), and #7 (divergent thinking). This description of Mr. Field's instruction using these OTOP items will answer the second research question about Mr. Field's explicit teaching strategies for scientific argumentation. A general description of his teaching strategies in the context of scientific argumentation will be provided in this section. Then, the OTOP data from 60 total hours of class observation during this study and the 23 sample hours containing scientific argumentation were compared. First, Mr. Fields' instruction across all lessons (60 hours) and the sample lessons (23 hours) in the third class period was compared (Figure 41). Mr. Fields' instruction between all lessons and the sample lessons for the fourth period was also compared (Figure 42). The results showed little difference in the teaching strategies employed by Mr. Field between all lessons and the sample lessons and between the third and fourth periods. The OTOP profiles of reform-based teaching strategies in 23 sample lessons were then compared between the third and fourth class periods (Figure 43), showing little difference in Mr. Field's explicit teaching strategies for scientific argumentation.

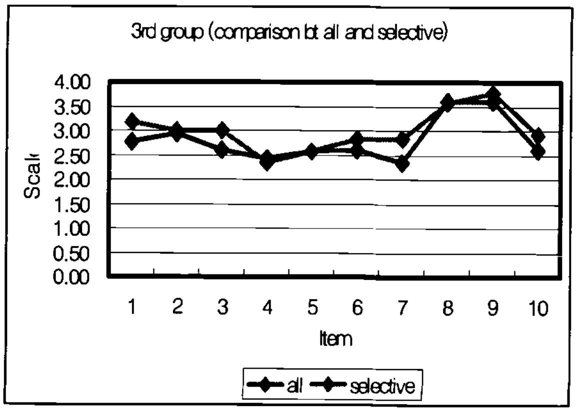


Figure 41: Third period: all & sample lessons

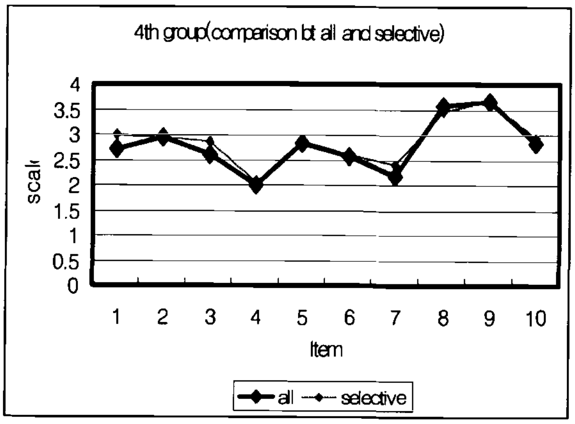


Figure 42: Fourth period: all & sample lessons

OTOP items: (1) Habits of mind (2) Metacognition (3) Discourse and group work (4) Challenging ideas (5) Misconception (6) Conceptual thinking (7) Divergent thinking (8) Interdisciplinary connection (9) Pedagogical Content Knowledge (10) Concrete material use

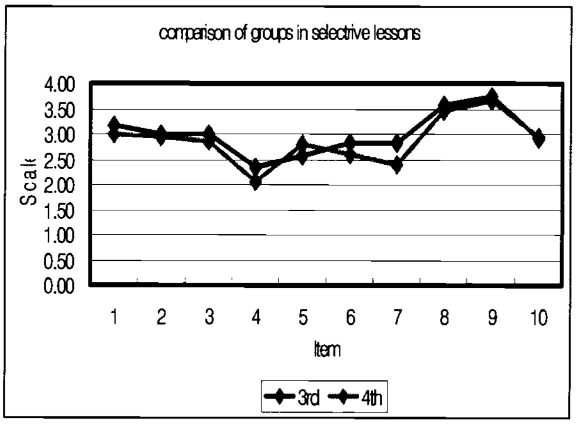


Figure 43: Group comparison: third & fourth periods
OTOP items: (1) Habits of mind (2) Metacognition (3) Discourse and group work (4) Challenging ideas (5) Misconception (6) Conceptual thinking (7) Divergent thinking (8) Interdisciplinary connection (9) Pedagogical Content Knowledge (10) Concrete material use

Looking at the two groups of students compared using OTOP shown above, there are similarities in the teaching pattern of Mr. Field's lessons in his emphasis on argumentation strategies in the 23 selected lessons and on average across all 60 lessons.

Mr. Field used many questions to assess students' prior knowledge or misconceptions—using OTOP #3 (Discourse and group work), #4 (Challenging ideas), and #5 (Misconception)—in each lesson where students developed their background information for the *Claim-Evidence Approach.* He provided open-ended questions to solve in *Daily Science*—using #1 (Habits of mind), #6 (Conceptual thinking), and #7 (Divergent thinking)—and encouraged students to express their ideas or demonstrate reasoning skills, using #2 (Metacognition). Mr. Field helped students develop their background knowledge through reading the textbook and transforming the data into other representations, such as bar graphs or drawings, using #8 (Interdisciplinary connection). In addition, he emphasized the use of appropriate information or knowledge in helping students understand the content and employed different discursive practices, appealing to #9 (Pedagogical Content Knowledge). Finally, Mr. Field used visual tools, such as videos or slides, in delivering the content and also used concrete materials for students' experiments, fulfilling #10 (Concrete material use).

Summary: Discussion of Teaching Strategies

Seven teaching strategies were observed in this study that allowed students to develop scientific argumentation. In *Daily Science*, Mr. Field aimed to make students to feel more comfortable making mistakes or predicting what would happen through the use of open-ended questions covering content on physical science and on scientific inquiry skills. Second, the *Claim-Evidence Approach* consisted of three steps: *Framing the Investigation, Designing the Investigation,* and *Analyzing and Interpreting Results.* In the first step, *Framing the Investigation*, Mr. Field helped students learn background information by reading the textbook and reviewing the worksheets. Mr. Field believed that background knowledge is essential for students to be able to demonstrate reasoning. In the second step, *Designing the Investigation*, Mr. Field gave students practice with differentiating the independent variables from the dependent, a basic skill necessary to designing experiments. Mr. Field provided direction when students collected and transformed the data. In the third step, *Analyzing and Interpreting Results*, Mr. Field emphasized the students' abilities to differentiate the evidence from the data, and instructed students to support their claims, whether right or wrong.

The third teaching strategy, the *Inquiry Guideline* provided a model for *Explicit Reflective Assessment*, which Mr. Field designed to give students the opportunity to reflect on what data they found, how they used the data to support their claims, and how they could make the experiment better by overcoming its limitations. The fourth strategy was the *Johns Hopkins Learning Model* for group work, in which students were assigned different roles in order to gain understanding of how scientific knowledge is constructed socially. The fifth was *Wednesday's Oregonian,* which provided students with the opportunity to discuss a current scientific issue. Mr. Field also used this strategy to encourage students to gain extended knowledge that is needed to develop extended arguments. Sixth, Mr. Field used the *Scoring Guide* to guide students in achieving procedural skills that met the expected procedural and reasoning skill levels for that grade. Lastly, *Bloom's Taxonomy* gave students a more explicit understanding of the kinds of reasoning skills, from recall to application skills, that were expected of them to meet the envisioned and appropriate levels of reasoning for the seventh grade.

Finally, the results of this study showed that Mr. Field provided students with many opportunities to demonstrate their reasoning skills. Examples of students' opportunities to reason in Mr. Field's classes included: how to gather background information, how to frame questions based on the information, how to differentiate the independent from the dependent variables in each lab activity, how to differentiate the evidence from the data, how to use evidence to support questions they developed, and how to create better experiments in a new context by overcoming the previous limitations.

Analysis of Classroom Discourse

This section describes this study's analysis of student discourse in response to Mr. Field's teaching. Student argumentation was analyzed in three dimensions: (a) logically using *Toulmin*'s approach, (b) sociologically using *Epistemic Operation*, and (c) psychologically and pragmatically using *Reasoning Complexity*. This section consists of six subsections. The first three sections describe student argumentation using these three different approaches, and the next two sections connect students' opportunities for argumentation to Mr. Field's teaching strategies. The last section relates the three different approaches to one another in terms of student argumentation. Verbal transcripts of the 23 sample lessons out of the total 60 hours of lessons were used as the data. The 23 sample lessons were selected based on the researcher's interpretation of which lessons included the most interactive argumentation between Mr. Field and his students. Scientific Argumentation Tables (SATs) were developed that included verbal transcripts of argumentation between Mr. Field and his students. Concrete examples of the SATs describing how students developed their arguments are provided in the context of the two main teaching strategies used by Mr. Field, the *Claim-Evidence Approach* and *Daily Science*.

The Analysis of Student Discourse Using Toulmin's Approach

This first section examines student argumentation in response to Mr. Field's teaching with the use of *Toulmin*'s approach. The transcripts of the 23 sample lessons consist of students' argumentation during whole class discussion. All 23 selected lessons consisted mainly of interaction between Mr. Field and his students, not among students in groups. The definitions of each component and its uses in *Toulmin's* approach were provided in the section on *Data Analysis* in Chapter III. Student argumentation analyzed using the *Toulmin* method revealed two different patterns of arguments: (a) less extensive arguments, which was the more frequent pattern; and (b) the more extended arguments, which was the less frequent case.

Two Types of Student Argumentation

The following example excerpted from an SAT (Appendix I) demonstrates the more frequent case of argumentation according to the *Toulmin* analysis. In this excerpt, Mr. Field discussed one experiment during *Daily Science*, one of his teaching strategies.

> A scientist wants to see which of 2 bean plants grows tallest. What's wrong with this experiment? Two different plants are placed in identical pots of soil, watered the same day and given the same fertilizer. One is put under a grow lamp and the other put in the Sunlight (open-ended question in Daily Science, October 19, 2004).

The full interactive discourse between Mr. Field and his students is provided in Appendix I, but the following table shows a part of the discourse during the lesson (Figure 44). For this open-ended question, Mr. Field phrased questions so that students were able to answer with one-word answers. Here, Mr. Field asked what variables need to be controlled to design this investigation. To this question, students responded with one-word answers, such as soil, fertilizer, plant, plants, or water. All of the responses by students at this point are *Claims* in the *Toulmin* system. Mr. Field evaluated students' responses positively by saying "good" or "OK" and kept asking other students to answer. When he encountered a wrong answer from any student—one student responded that "light" is controlled—Mr. Field evaluated it negatively, saying "no." However, he did not explain why light was not a controlled variable. The discourse between Mr. Field and his students consisted of the teacher's question, students' answers providing a *Claim*, and then the teacher's evaluation without more explanation, which could be called the *Warrant*.

This example comes from one of the discussions during *Daily Science* when the teacher checked the answer with the students. During *Daily Science*, Mr. Field interacted with students in order to provide them with the opportunity to practice differentiating the independent variables from the dependent ones, a skill needed in designing investigations. During *Daily Science*, students usually provided one-word answers as a type of *Claim* (47% of the total 70 arguments). Mr. Field mainly repeated students' answers or added brief explanations as a type of *Data* (31% of the total 70 arguments). The students could have had chances to develop other arguments, such as *Warrants* explaining a phenomenon, *Qualifiers* adding more information, *Rebuttals* refuting other *Claims*, or *Backing* generalizing ideas; however, these elements occurred rarely or not at all during *Daily Science*.

TEACHER	STUDENT	TOULMIN
Tell me one thing you are trying to control in this experiment		
	The soil.	Claim
The soil, good. Alex, another thing they were controlling in this experiment?		Claim
	The light?	Claim
No. Penny, another thing they were controlling in this experiment?		
	Fertilizer	Claim
Same kind of soil. OK, Stacy, another thing they were controlling		
	The light.	Claim
I said the light wasn't one of them. Nichole, another thing we were controlling?		
	The plants?	Claim
The plants, I'll take that. Riley, another thing?		

	The kinds of soil	Claim
Same size. Another one?		
	The amount of water.	Claim
The amount of water. Different plants, we control the kinds of plants. We are going to have plant 1 and plant 2. Identical pots. Same soil, same watering, and same fertilizer. You were supposed to write down the things that were controlled. What was the problem with this experiment?		
	There were two different kinds of sunlight and two different kinds of plants	Data

Figure 44: Excerpt from SAT: Appendix I (October 26, 2004, 4th period)

Figure 44 divides Mr. Field's discourse and students' discourse into columns in order to examine the contributions to the discussion and to see who developed what types of argument. Mr. Field's arguments included *Data* most frequently (53% of Mr. Field's arguments), *Claim* or *Warrant* second most frequently (19% each), and then *Qualifier* (6%), *Backing* (3%), and no *Rebuttal.* On the other hand, student arguments used the *Claim* most frequently (89% of the total student arguments), with other arguments being *Data* (7%) and *Warrant* (4%), with no instances of *Qualifier, Backing,* or *Rebuttal.* As described earlier, in the more frequent case of argumentation during *Daily Science,* students provided short answers to Mr. Field's questions and he provided more description to elaborate on students' ideas without giving them opportunities to develop more extended arguments, such as using *Qualifiers, Backing,* or *Rebuttals.*

The following example (Figures 45 and 46) demonstrates the less frequent case of argumentation, showing a more extended argument that emerged during CLEA (Figure 46 from Appendix J: October 12, 2004, fourth period), but including a less extended one as well (Figure 45). After the *Rocket Balloon Activity*, Mr. Field and his students discussed the limitations of the investigation of what made the balloon stay longest in the air. Mr. Field did a demonstration for the class to see if gravity acts equally on two objects with different masses. Here, the discourse between Mr. Field and his students consisted of less extended arguments, such as *Data*, in response to his question (Figure 45).

During the latter part of the discussion, Mr. Field created a situation where students developed conflicting theories to support their stance. One position was that gravity is constant regardless of mass, and the other was that gravity is dependent on the mass of the object. In this context, students interacted with Mr. Field or with other students to confirm or disconfirm their argument or the arguments of others with appropriate evidence. At this moment, Mr. Field provided more chances for students to develop more extended arguments, such as *Qualifiers* and *Rebuttals* (Figure 46). A more detailed description of these two examples, the less and more extended cases of argumentation that occurred during CLEA, is provided with concrete examples below.

Mr. Field asked his students to come up with factors that would make the rocket balloon stay longest in the air. To this question, students responded, "Acceleration," "Time," "Distance," and "Force," as *Data* arguments. Mr. Field repeated students' answers and then kept asking for more factors. When one student responded with a factor, "Motion," Mr. Field asked the student to find a better word without giving the student more information. At this time, another student replaced "Motion" with "Energy," and then Mr. Field repeated it. This discourse between Mr. Field and his students during CLEA displayed the less extended case of argumentation consisting of questions, answers, and evaluation.

TEACHER	STUDENT	TOULMIN
Oh, very good. The last class didn't get reference point. You don't have to write these yet. Let's just generate them first. More words? Anything that you think is going to help you describe what you think is going to happen with this rocket balloon.		
	Acceleration	Data
Acceleration. Another one?		
	Time.	Data
Yes, you have to have time. Yes?		
	Distance.	Data
Distance. Yes.		
	Force.	Data
Force, oh, yeah, we better have that word in there somewhere.		
	Motion	Data
Motion. Any other words that you think might play a part.		
	Energy.	Data
Energy, okay. We said there were two kinds of energy. We haven't focused on them very much, but I'll write them down here – potential and . . .		
	Kinetic	Data
Kinetic. Potential and kinetic energy.		

Figure 45: Excerpt A from Appendix J (October 12, 2004, 4th period)

Students, however, later had more opportunities to develop extended arguments during CLEA when compared to the case of argumentation during Daily Science. The following discussion (Figure 46) shows how Mr. Field led students to discuss the factors that made it possible or impossible for the balloon stay longest in the air. Mr. Field checked to make sure students had collected evidence from their experiments in the *Rocket Balloon Activity* under the *Inquiry Guideline.* Mr. Field regarded the amount of tape students used as one of the factors influencing the balloon's flight, and he asked why the smallest amount of tape was needed to make the balloon stay in the air longer. This argument, a *Qualifier* (the *smallest amount* of tape makes the balloon stay in the air longer), strengthened the relationship between *Data* (the amount of tape) and *Claim* (the amount of tape used to hold the nozzle to the balloon).

At this time, Mr. Field furthered the discussion by asking students more about the force involved in pulling the balloon downward. Mr. Field reminded students of the definition of the force of gravity, *You are talking about some force here. What force are you talking about?* Mr. Field confirmed students' understandings about the definition of the force of gravity, *You are talking about the force of gravity and you seem to think that if something weighs more, the force of gravity pulls on it more. Is that right?* Then, Mr. Field provided an example from the real world to help students understand the properties of gravity by prompting, *OK, is that what you all think? If I went to the top of the school and I dropped a golf ball and I dropped a ping pong ball, the golf ball would hit the ground before the ping pong ball.* Mr. Field stated the two conflicting theories about gravity, which prompted students to find more evidence based on their prior knowledge and experience to support one theory or to refute the opposing one. Mr. Field began the argument with one theory: *OK, some of you believe that gravity pulls on everything with exactly the same amount of force.* In response to his instruction, a few students confirmed their understanding about gravity with their opinions, *It depends on what the mass is* or *It depends on how much [it weighs].* These *Qualifiers* offered by students were possible because Mr. Field created the discussion about gravity. One student provided an opposing theory as a *Rebuttal*, saying *In space you can drop a hammer and a feather and they will land on the ground at the same time.*

In response to these two opposing theories about gravity, either that it is constant or dependent on mass, Mr. Field gave a demonstration to show how gravity is constant. The teacher's demonstration led students to reason based on their observations, and Mr. Field concluded that gravity is constant because the two balls landed at the same time. During this discussion, students used *Qualifiers* and *Rebuttals,* creating a more extended form of argument.

Mr. Field's purpose in using the CLEA was to provide students with the opportunity to develop their own claims to be tested and to find evidence from their experiments to support their claims. During this particular CLEA, Mr. Field followed his *Inquiry Guideline*, which gave students a chance to reflect on their own claims and whether they were testable or not, on their evidence to support their claims, and on the limitations of the experiment in order to improve it. When students discussed the limitations of the experiment *Rocket Balloon Activity*, the students offered more extended arguments such as *Rebuttals* and *Qualifiers* with the aid of Mr. Field. Mr. Field's prompting questions related to gravity and demonstration of a simple experiment made it possible for students to retrieve the knowledge needed to understand the phenomenon. In this example, students were engaged in providing the more extended arguments, including *Warrants (*12% of the total number of *Toulmin* codes for this discussion*), Qualifiers* (14%), *Rebuttals* (9%), and *Backing* (10%) with fairly even frequency, as well as the less extended arguments of *Claims* (17%) and *Data* (39%).

TEACHER	STUDENT	Toulmin
I am going to use as small amount of tape as possible and still make that tight, so air can't escape. Why would I want to use the smallest amount of tape possible? Yes?		Qualifier
	So it doesn't weight it down	
So it doesn't weight it down. What do you mean by weigh it down?		Qualifier
	So that it doesn't go [down]. If its mass isn't too much. .	
You are talking about some force here. What force are you talking about?		
	gravity	Data
You are talking about gravity and you seem to think that if something weighs more, gravity pulls on it more. Is that right?		
	Yes	
OK, is that what you all think? If I went to the top of the school and I dropped a golf ball and I dropped a ping pong ball, the golf ball would hit the ground before the ping pong ball. Is that right?		Data
	No	
	[All talking at once]	
OK, some of you believe that force of gravity pulls on everything with exactly the same amount of force		Backing
	It depends on what the mass is	Qualifier
You are saying that the mass makes a difference		Qualifier
	If it is [different in mass].	Qualifier
Sebastian?		
	It depends on how much [it weighs]	Qualifier
.	In space you can drop a hammer and a feather and they will land on the ground at the same time	Rebuttal
We have a difference of opinion here. Let's see if I can find two things that are different masses here. Let's make sure they are quite a bit different. I've got this book, and that is quite a bit of mass there, isn't it? A lot more mass there than say the top of my pen. Would everyone agree that these are quite different in mass?		Data
	[Unanimous yes]	
If I drop these, one should hit the ground before the other, right? [Noise] What did you see?		Data
	The same time	Data
	The book	Data
	The same time	Data
They hit the ground at the same time. That's because gravity is a constant. It pulls on all things with exactly		Data Rebuttal

the same amount of force. Even though you think that is not true, that is. Gravity doesn't care if you are big or small.		
	If a short person falls off a building and a heavy person falls off a building, they will both hit the ground at the same time?	Data
What about a feather? That is what most people say. If you drop a bowling ball and a feather at the same time, they are not going to hit the ground at the same time. Well, they said, that is because of air resistance. It is underneath the feather and makes it flutter down. Let's see what happens if we take all the air away. Have a bit huge column and they pump all the air out. They have a little thing that they pull so both things fall at the same time. The feather and the ball hit the ground at the same time.		Rebuttal Claim Rebuttal

Figure 46: Excerpt B from Appendix J (October 12, 2004, 4th period)

A general description of student argumentation in response to Mr. Field's instruction was based on 23 SATs analyzed using the *Toulmin* approach. The frequency of occurrence of each category was counted to assess the quality of student argumentation. In terms of the *Toulmin* analysis, total student argumentation in response to Mr. Field's teaching strategies consisted of *Data* (51% out of 1532 total argument elements), *Warrant* (21%), and *Claims* (13%) as making up the more frequent case of argumentation relative to the other components: *Qualifier* (9%), *Rebuttal* (4%), and *Backing* (2%). These percentages display *weak* or *less extended argument forms*. This means that Mr. Field's strategies focused on providing students with many brief but less developed opportunities to practice scientific discourse.

The less extended arguments were most often observed during Mr. Field's instruction of *Daily Science,* whose purpose was for students to practice the basic skill of differentiating independent variables from dependent. On the other hand, the more extended arguments were most often observed during Mr. Field's instruction of the CLEA, including the *Inquiry Guideline*, where students reflected on the whole process of investigation. Students examined their claims to see how well their claims were connected to the content that they were learning. Students discussed if they found evidence to support their claims, and what patterns of data they collected during their experiments. They also looked at the limitations of the experiment in order to improve it. However, the students' limited scientific knowledge and not enough "wait time" for students to retrieve prior knowledge were identified as barriers, preventing students from developing more extended arguments.

The Analysis of Student Discourse Using Epistemic Operation

Students' argumentation was also analyzed by *Epistemic Operation* (Figure 5 in Chapter III; Jimenez-Aleixandre, Diaz de Bustamante, & Duschl, 1998). The *Epistemic Operation* method is a sociological approach that is used to examine how interaction in the social setting influenced the students' opportunity to develop argumentation. Scientific knowledge is constructed through action carried out in discourse, where participants negotiate (Pontecorvo & Girardet, 1993). To analyze the student argumentation by *Epistemic Operation,* first this section describes how the student discourse was analyzed with one example from *CLEA*. Second, *Epistemic Operation* is used to examine student argumentation overall in the 23 sample lessons recorded during class observations.

The first example used for *Epistemic Operation* (Appendix K) covered student discourse in the *Marble Activity* during CLEA. Mr. Field demonstrated how one marble rolls to hit the other marble in terms of action and reaction, and encouraged students to predict what would happen and why in their own terms. After this simple demonstration, students in groups received up to ten marbles to design their own experiment and to test their claims based on Newton's third law. Each group of students got a certain number of marbles and arranged them in different orders, such as two marbles on the top of the rail, three marbles in the middle of the bottom of the rail, and another two marbles at the end of the rail (See Appendix L). Students predicted in groups what would happen first and why it would happen. After testing their predictions, students discovered whether their hypotheses were right or wrong. During this process, students predicted and tried to explain how marbles on the track act or react to each other in terms of energy transfer. The following excerpt from Appendix K shows how students developed argumentation through interaction with Mr. Field (Figure 47).

As seen in Figure 47, students described what they thought would happen based on their prior knowledge and observations as a "tool" in justifying the mechanism of the phenomenon, frequently using *Appeal* (as *instance*) from *Epistemic Operation.* The "tool" included student's brief answers without any explanation, such as *Number one hit two and then they all grouped together.* On the basis of students' answers, Mr. Field or other students evaluated their explanations or predicted what would happen before the experiment, which accounts for the more frequently used *Plausibility* from *Epistemic Operation,* such as *What do you think is going to happen? Don't forget the number, number one, two, three. What will happen? Make a prediction first.* This prompting by the teacher or other peers made it possible for students to develop further argumentation without closing the discussion.

In addition, Mr. Field or students stated a few principles related to energy transfer while they tried to explain the phenomenon, which is a type of *Deduction*, another frequently used element during the lesson. Mr. Field and his students did some simple experiments to find evidence to support their claims. Most frequently used were *Plausibility*, used by students during student discussion in groups, and *Causality,* used by Mr. Field to add knowledge that students could use to understand the phenomenon.

Overall, during the *Marble Activity* in the middle phase of CLEA (Appendix K), Mr. Field asked students questions, and students responded to his questions with one-word answers. At this time, students' responses worked as "means" or "tools," which were used to explain the mechanism for the phenomenon (*Appeal* to the *instance* made up 26% of 119 total operations). In addition, students added description to justify how marbles on the top of the rail hit one another in the middle, or the others at the end of the rail, using the concept of energy transfer (*Causality*, 41% of total operations). These two operations, *Appeal* and *Causality*, were the most frequently used during the *Marble Activity.* At this time, Mr. Field could only provide students with opportunities to develop arguments through factual or conceptual knowledge as one-word answers, and then he used students' ideas to explain the cause and effect mechanism of *Marble Activity.*

Teacher	Student	Epistemic
I'm trying to think of all the possible patterns that I've come up with, and here is the next one that I can think of. We haven't done this one yet. Let's put one there and two there, and three there and see how it [comes] through.		Causality Appeal
	I think the energy that is transferred will get. .	Causality

	.	
Make a hypothesis of what you think is going to happen.		Plausibility
	What do you think is going to happen? Don't forget the number, number one, two, three. What will happen? Make a prediction first. If I release the ball, what will happen to number one, number two, number three	Plausibility Appeal Plausibility Plausibility
	I think they would all end up together.	Deduction
	All three?	Appeal
	All three together.	Appeal
	How about if the speed is different? What about the speed? If I released a ball here? Would they go together?	Plausibility Plausibility Plausibility Plausibility
	Yes, they will go together,	Causality
Watch very carefully what happens. There is a lot of action and reaction as these go down. We have marbles that bounce backwards and then bounce forwards. Watch carefully to see what happens.		Causality Appeal Causality

Figure 47: Excerpt from Appendix K (November 8, 2004, *Marble Activity*)

Epistemic Operation was used to analyze another sample of student discourse that occurred during *Daily Science*, in which students practiced designing an investigation to test which of three different golf balls would travel the farthest. Mr. Field began the discussion by asking students what variables were needed, and how the independent variable was different from the dependent, in general. Then, Mr. Field led students to apply their understanding about golf balls, clubs, constant power, and types of surface to specific instances while designing an experiment. The argumentation during this process showed *Appeal* (as *instances* or *exemplars*) was most frequently used. Mr. Field added explanation to or elaborated on students' ideas by providing more extended experience and knowledge, which accounted for the also frequently used element *Consistency* (with extended *knowledge* or *experience*). Since the purpose of *Daily Science* was to make students practice differentiating the dependent variables from the independent ones, students could only provide simple examples or instances of "variables" as being dependent or independent in the experiment. The other operations, such as *Causality* and *Consistency* with other knowledge or experience, were developed by Mr. Field.

The general pattern of student argumentation as analyzed by *Epistemic Operation,* based on the selected 23 hours of classroom observations, consisted of *Appeal* (33% of 1500 total operations) as the most frequent operation, and *Causality* (26% of total) as the second most frequent. This pattern means that students, in general, produced short answers (*Appeal* as instances) to Mr. Field's questions or prompts, and then Mr. Field used students' ideas to explain the mechanism of certain phenomena (*Causality*) during the discussion. The relationship among three operations, *Causality* (by Mr. Field) with *Appeal* (by students) and *Consistency* (by Mr. Field), contributed significantly to the discussion in Mr. Field's classroom in terms of *Epistemic Operation* analysis.

The Analysis of Student Discourse Using Reasoning Complexity

Hogan, Nastasi, and Pressley (2000) inductively developed categories of reasoning from their study with the use of various frameworks that describe the essential components of scientific reasoning derived from Resnick, et al. (1993). Studies of reasoning through discourse depend significantly on the nature of the situated context, where the reasoning is carried out with peers for the purpose of communication.

Hogan, Nastasi, and Pressley (2000) defined the first two criteria in *Reasoning Complexity* (*Generativity* and *Elaboration*) as declarative knowledge, which is defined in terms of "knowing that," such as specific content or more general concepts. The second two criteria (*Justification* and *Explanation)* in *Reasoning Complexity* are defined as procedural knowledge, which is the "knowledge of how" to do something using known procedures. The last two criteria (*Logical coherence* and *Synthesis*) in *Reasoning Complexity* are defined as the skills in argumentation. In this section, first the student discourse is described according to the *Reasoning Complexity* system, to show how it was analyzed with the use of two concrete examples of SATs from CLEA and *Daily Science.* Second, student argumentation is analyzed in general using *Reasoning Complexity* based on the 23 sample lessons from the class observations.

The first example of argumentation is from a CLEA activity covering the content of Newton's first law right after the *Rocket Balloon Activity* (Figure 48). Students had a chance to write their lab report under the guidelines given to them by Mr. Field. Mr. Field helped students identify and express their own claims and the evidence to support their claims.

> You need to address both sides of Newton's first law – what happens when it is not moving and what happens when it is moving. OK, that's the claim. I am saying this is what Newton says, and now we are going to do the rocket balloon lab to try to find out if the book is lying to us or not, or if we can actually prove what he says is true. That is called the evidence.

Then, Mr. Field asked students what evidence they could use to explain the phenomenon, how to make the balloon stay longest in the air. Students provided some ideas (*Elaboration*), such as *reference point, acceleration, distance, time, force,* and *energy*, but Mr. Field only repeated students' ideas without explaining the reason why those ideas were used as evidence.

The discourse above occurred during the last phase of CLEA, when Mr. Field guided students in writing their lab reports using the *Inquiry Guideline*. During this phase, students had the chance to reflect on their claims and evidence from experiments and discuss how that evidence was used to support the claims. Students also had the chance to discuss the limitation of the experiments. The reasoning skills identified during the last phase of CLEA included *Elaboration* as most frequently used (33% of 118 total arguments), plus *Justification* (16%), and *Generativity* (12%), used mainly by students. The other reasoning skills of *Explanation* (23% of total arguments), *Logical Coherence* (10%), and *Synthesis* (6%) were employed mainly by Mr. Field. This distribution of reasoning skills indicates that student argumentation consisted of requests for conceptual knowledge (*Generativity* and *Elaboration*), or "knowing what"; while both students' and Mr. Field's reasoning skills (*Justification* and *Explanation*) used procedural knowledge, or "knowing how." However, only Mr. Field used the highest quality reasoning skills (*Logical Coherence* and *Synthesis*). Mr. Field only requested students to develop their argumentation through reasoning skills using conceptual knowledge.

TEACHER	STUDENT	REASON
Good. You need to address both sides of Newton's first law – what happens when it is not moving and what happens when it is moving. OK, that's the claim. I am saying this is what Newton says, and now we are going to do the rocket balloon lab to try to find out if the book is lying to us or not, or if we can actually prove what he says is true. That is called the evidence. What evidence can we gather through this investigation to either prove or disprove this claim? When you are talking about, let's go back through Chapter 1 and Chapter 2 and begin to develop a list of vocabulary words that you might want to have in your framing that would help explain your position on whether this claim is true of not. Go back into your books and raise your hand if you can think of a word that we might want to use to describe this.		Elaboration Explanation Elaboration Logical Synthesis Elaboration
	Velocity.	Elaboration
Velocity. Now remember what velocity is? That is average speed, but you tell what direction, right. Another one?		Justification
	[reference point]	Elaboration
Oh, very good. The last class didn't get reference point. You don't have to write these yet. Let's just generate them first. More words? Anything that you think is going to help you describe what you think is going to happen with this rocket balloon.		
	Acceleration	Elaboration
Acceleration. Another one?		
	Time.	Elaboration
Yes, you have to have time. Yes?		
	Distance.	Elaboration
Distance. Yes.		Elaboration
	Force.	Elaboration
Force, oh, yeah, we better have that word in there somewhere.		
	Motion	Elaboration
Motion. Any other words that you think might play a part.		
	Energy.	Elaboration
Energy, okay. We said there were two kinds of energy. We haven't focused on them very much, but I'll write them down here – potential and . . .		Elaboration

Figure 48: Excerpt from Appendix M (October 12, 2004, 4th period)

The second example analyzed with *Reasoning Complexity* covered one of the lessons in *Daily Science* (Figure 49). Mr. Field encouraged students to think of variables, independent and dependent ones, which were needed to design the investigation to test which golf ball travels the farthest. Students expressed different opinions (*Generativity*) about which variables could be dependent or independent, such as *The golf balls, What kind of land you are going to have,* and *What direction you are going to hit the ball.* Then, Mr. Field repeated students' ideas with more knowledge (*Elaboration*) to prove if their ideas were reasonable or not (*Justification*). For example, Mr. Field asked how the golf balls could be used as variables in designing the investigation by saying, *Did you identify on your first one the three kinds of golf balls you were choosing to use? Or did you say select three different kinds of golf balls?* One student could develop *Justification* in response to Mr. Field's prompting. That is, one student answered, *What direction you are going to hit the ball?* Then Mr. Field prompted, *why would that be important?* Then, the student justified his choice by saying, *Because you might hit something.* Mr. Field considered the response incomplete, so he prompted again, *If you say it is important to hit the balls south, for instance, why would that be important?* With this prompt, the student could make his justification more sophisticated, *Then we would know that all the balls are going one way.* In this case of argumentation, students mainly used the operations *Generativity* (58% of 48 total reasoning skills) and *Elaboration* (23%). The operations *Justification* (13%) and *Explanation* (4%) were mainly used by Mr. Field. The operations *Logical Coherence* and *Synthesis* were not found in this sample, since students were practicing discovering and differentiating dependent variables from independent ones during this *Daily Science*. Students did not have the opportunity to use the higher quality reasoning skills of *Logical Coherence* or *Synthesis*, which were found more often during CLEA.

TEACHER	STUDENT	REASONING
You write down determine the variable, so do you expect the person who is doing the lab to determine the variables or you were supposed to determine the variables? You are? OK, what variable have you determined?		
	The golf balls.	Generativity
Did you identify on your first one the three kinds of golf balls you were choosing to use? Or did you say select three different kinds of golf balls? Have you don't that for step one? Don't you think that would be the most important thing to do if you were trying to measure the distance of three golf balls, to say you have to select three golf balls? [omitted] Mercedes?		Justification
	What kind of land you are going to have.	Generativity
Somewhere in your description, you should be talking about the surface you are going to be hitting on, right? If you say go to the golf range, that would work. Or go out to an open field or whatever you were going to do. You should tell where you are going to hit. Anything else we need to do?		Justification
	What direction you are going to hit the ball?	Generativity
OK, why would that be important?		
	Because you might hit something.	Justification
If you say it is important to hit the balls south, for instance, why would that be important?		Elaboration
	Then we would know that all the balls are going one way.	Elaboration
What I hear you saying is you want to be sure you hit all the balls in the same direction. You are trying to control the conditions, right?		Justification
	Yes.	
Tessa, did you talk about hit all the balls during the same day, or are you going to hit a Titleist on Monday when it is Sunday with a tailwind and you are going to hit the Top Flight on Tuesday when it is sunny and there is no wind, and you are going to hit the Ben Hogan on Wednesday with a storm coming in and the wind is blowing in your face? Would that affect your results?		Elaboration
	Yeah.	
Good, so you should say there somewhere, hit all the balls at the same time, so that you control the environmental conditions. What else have you got. There is one other real important thing.		Explanation
	Wind?	Generativity

We kind of just talked about that. Anything else you can think of that we need to put down in our designing?		
	How hard it is.	Generativity
Something about the force of the hit, right? We talked about that. We talked about if a machine is going to hit it with the same force or if you are going to use a professional golfer, would he hit it with the same force? Yes.		Elaboration
	What type of club?	Generativity
What kind of club you are going to use, good. What kind of club. If you hit it with a pitching wedge it is going to be a lot different than hitting it with a driver, if you know anything about golf. The driver hits it 250 yards and a pitching wedge hits it 70 yards. That could be a factor. Do you want to talk about how many trials you are going to do? Are you going to hit the ball once? How many times do you think you should hit each ball to make it [fly farther]?		Elaboration
	Three times.	Generativity

Figure 49: Excerpt from Appendix N (October 26, 2004, 3rd period)

Overall, the argumentation analyzed by *Reasoning Complexity* consisted of *Elaboration* occurring most frequently (38% out of 1563 total reasoning skills), *Justification* second (19%), *Explanation* third (17%), and relatively little use of the other three, with *Generativity* (12%), *Logical Coherence* (10%), and *Synthesis* (4%). The high percentage of the reasoning skill *Elaboration* accounts for students' ideas that supported conclusions or claims (*Generativity*) in response to Mr. Field's initial questions or prompts during the lesson. Based on students' ideas, other students or Mr. Field provided *Justification* as a description of "how," the second highest operation. Then, Mr. Field added the knowledge of how to apply *Justification* into new context, *Explanation*, the third most operation. These four operations—*Generativity, Elaboration, Justification,* and *Explanation*—were found frequently during both CLEA and *Daily Science.* However, the last two reasoning skills—

Logical Coherence and *Synthesis* for high quality argumentation—were developed mainly by Mr. Field and found only during CLEA rather than *Daily Science*.

The Relationship Between Written Argumentation & Students' Scientific Knowledge

Students' written argumentation varied in quality, resulting from students' different academic achievement levels and reading and writing abilities based on state tests scores. The researcher assessed two groups (third and fourth periods) of students' two different lab report assignments. After scoring the labs, with a full score of five, the labs were divided into three groups: **Complete** (scored 4-5), **Partial** (2-3), and **Limited** (0-1). The researcher used only the data from the first part of the lab reports (*Framing the Investigation*) and the last part (*Analyzing and Interpreting Results*) to describe how student written argumentation varied in quality. To assure the validity of data analysis, the researcher compared her assessments with Mr. Field, whose full score was 10, and no difference was found between the assessments.

Every student's lab report included all six components of *Toulmin's* approach; *Data, Claim, Warrant, Qualifier, Backing,* and *Rebuttal.* However, there were differences in the quality of written argumentation. The following three examples of written argumentation are from students' lab reports (Figures 51, 52, and 53). The subtitles of the lab report are highlighted in bold in the figures below. The letters A, B, and C with the numbers 1 through 4 indicate the key elements of the following discussion about how students developed argumentation through writing and how the quality of that argumentation differed.

The **Complete** lab report (Figure 50) consisted of all six components of *Toulmin's* approach. Mr. Field guided students to write their lab reports within a certain framework through his self-designed *Inquiry Guideline*, creating an opportunity for *Explicit Reflective Assessment.* On the basis of this guideline, students developed their arguments, or *Claims* (A) to be tested based on the *Backing* (Newton's first law; not shown here), and they predicted what would happen and why with background information that they got from the textbook or from discussion with Mr. Field (B).

During *Framing the Investigation,* students were supposed to use at least five new scientific terms in their writing (<u>underlined</u> in Figure 50) that they learned from reading the textbook, and to describe scientifically what would happen and why. In this case, the student provided reasonable scientific terms to predict what length nozzle would make the balloon stay longest in the air and to justify why.

During *Analyzing and Interpreting Results*, the student described in writing exactly what happened and what length nozzle made the balloon stay in the air longest, using the argumentative element *Data* (Figure 50, C-1). The student reported what lengths of nozzle made the balloon stay in the air the shortest amount of time and tried to report patterns from the data among the six different nozzle lengths, using *Qualifier* (C-2). Then, the student explained why a certain length of nozzle made the balloon stay in the air longest with reasonable scientific terms, using *Warrant* (C-3). Finally, the student discussed any limitations that might have prevented the investigation from getting the best results, which could be overcome in a better-designed experiment in the future, which is *Rebuttal* (C-4).

Framing the Investigation
An object at rest will stay at rest unless a force acts on it. An object at a constant speed will stay at a constant speed unless at outside force acts on it **(A)**

I think that the balloon with a nozzle of 35 cm will stay in the air the longest. I think this because there is the same volume of air in the actual balloons, but there is a greater <u>volume</u> of air in the longer nozzles. The air in the rockets is under pressure causing it to flow out of the object at a certain <u>speed.</u> As long as the air is flowing out of the rocket, it can defy the <u>force</u> of <u>gravity</u>. Since the rocket with a nozzle of 35 cm has the greater air volume, it can defy gravity the longest.
I also think that the rockets <u>velocity</u> will effect how long it stays in the air. Using the top of the desk as a <u>reference point</u>, then if the rocket flies straight in a downward direction then it will cut the time short. If the rocket <u>accelerates</u> in an upward direction then the time the balloon is in the air will be longer **(B)**

Analyzing and Interpreting Results (C)

1. The rocket with the nozzle length of 10 and 15cm. stayed in the air the longest (2.96sec). The rocket with a nozzle length of 30cm. stayed in the air for the shortest time (2.27sec).
2. I did not see any patterns: the numbers seemed random. I noticed that the results for the nozzle lengths 10 and 15cm. ended up the same.
3. I think the results turned out random due to the rockets velocity. Sometimes, the rocket would fly up and stay, and sometimes the rocket would fly straight up then down. If the balloon stayed then it had a longer time. If it went straight up and down then the time was cut short. I think that how much the rocket weighed affected this.
4. Some problems could be that we had to remake the balloon several times. Each time we changed the amount of tape that was on the rocket and the stretchiness of the balloon, this could cause a change in weight of the rocket. Also each time we most likely did not blow the balloon exactly to 30cm. We probably did not cut exactly 5cm off the straw each time. One more thing is that there is no way we started and stopped the stop watch at exactly the right time.

Figure 50: One **Complete** lab report showing student argumentation
<u>Underlined</u>: new scientific terms student used for argumentation

The other two examples (Figures 52 and 53) also included all six components of *Toulmin's* approach, but their argumentation was limited in quality, resulting from students' different academic achievement levels and reading and writing skills. The letters A, B, and C and numbers 1 to 4 indicate the key elements of these students' argumentation in writing.

The **Partial** lab report (Figure 51) displayed weaker or less extended scientific argumentation than the **Complete** lab report (Figure 50). In Figure 51, this student did not use terms from the domain of science but from everyday life (A). This student also did not provide supportive evidence to predict what would happen and why it would happen (B). That is, she chose the second longest nozzle length (30 cm) as the nozzle she thought would make the balloon stay in the air longest, but she did not give a reason for choosing it. She also provided more pieces of evidence, such as volume, gravity, and distance, to explain how the balloon would stay in the air, which would have been appropriate if she had chosen the shortest length of nozzle. She did not provide exact evidence from the data to support her claim (C-1), and she repeated her answers in describing the pattern of data (C-2). If this student found no pattern in her data, she should have provided an explanation, but she did not (C-3). In describing limitations, she only pointed out the limitation of the balloon (C-4). Even though this student developed an argument using all six components of *Toulmin's* approach, the argument quality was weak when compared to the prior example.

Framing the Investigation
Claim: Things that don't move stay motionless. Things that are moving that one speed stay at that spend unless another unbalanced force intercepts with it **(A)**
Evidence: What I think will happen is that the middle length (20cm) will stay the longest because it won't have as much mass to hold up and it will let out the volume of the air fast enough to give it a good distance to shoot up and the stay its way down with gravity pulling on it. I think it will take more time to get down because it won't have to little or too much mass and it will give more force, but not too much too fast or too slow. It will take it more time though mostly because it will accelerate enough to interrupt inertia with gravity and cause it to pass the reference point later on **(B)**

Analyzing and Interpreting Results (C)
1. **Report the results**: The results came out as to it never went under I see and but never over 4.5 sec. The averages all came down to about 2.8 sec. The way that they came up with different times is the lengths of the nozzle.
2. **Identify pattern**: Some patterns I saw I wrote down in #1. The time never went under 1sec and never over 4.5 sec. Another was all the averages came down to 2.5 sec, odd seconds.
3. **Why it happened:** The experiment came down to that different nozzle lengths results to different times because at times it was long and a small or long or even in between lengths or short with long, short or in between lengths of the nozzle for the experiment.
4. **Any Limitation to cause problem:** If your balloon popped then you would have had to get a new balloon and it may gibe different results.

Figure 51: One **Partial** lab report showing student argumentation
Underlined: new scientific terms student used for argumentation

The following **Limited** lab report (Figure 52) also consists of the six components from *Toulmin's* approach, but its argumentative quality is very low. In fact, its meaning is difficult to follow even though there is a hint of a form through the use of the required terms. This student did not develop his *Claim* (A). He did not provide exact *Data* to support the claim, and his scientific terms from the textbook were not related to each other at all (B). Some arguments were missing (C-3). Other arguments were given without supporting evidence (C-1). He did not explain how the limitations prevented him from getting the best results (C-4). Furthermore, the student's writing skills were unstructured when compared to the other two students' examples.

Framing the Investigation
I think it would be medium length (A)
Everything has a mass in are everything will not move if it is just sitting thing. I now it would be the middle because of the force it has and energy. It has to acceleration can be a good and bad thing because it could matter of distance of direction , the mass of object and so we times it could matter be time and the reference point to determine the distances of the flight **(B)**

Analyzing and Interpreting Results (C)
1. **Report the results**: We took the results from all the teams and found the average and the fact said that 15 and 10 worked the best.
2. **Identify patterns:** I see no pattern so there nothing to tell about
3. [blank]
4. That the balloon size, popping, tape, straw were not even the area and the stop watch

Figure 52: One **Limited** lab report showing student argumentation
Underlined: new scientific terms students used for argumentation

In summary, the development of student argumentation observed in this study (a) was influenced by Mr. Field's scaffolding through prompts, questions, and clues; (b) was influenced by explicit teaching strategies, such as the *Claim-Evidence Approach, Daily Science, Explicit Reflective Assessment,* and (c) consisted mainly of weak arguments by students, such as *Claims* and *Data*, and strong arguments by Mr. Field, such as *Rebuttal* and *Backing*. The students' written argumentation in the lab reports was divided into three levels, **Complete, Partial,** and **Limited**, based on a full score of five. Students completed the lab report under the *Inquiry Guideline* developed by Mr. Field, which gave students practice developing written arguments that included all six components of *Toulmin's* approach. However, student argumentation varied in quality depending on students' academic and reading and writing levels, which was validated by Mr. Field in his last interview.

Summary: Analysis of Classroom Discourse

The scientific argumentation developed by Mr. Field and his students during this study was analyzed using three different approaches: *Toulmin*'s approach as a logical analysis, *Epistemic Operation* as a sociological analysis, and *Reasoning Complexity* as a psychological or pragmatic analysis. The last two approaches in this study, *Epistemic Operation* and *Reasoning Complexity*, are employed to understand the process of arguments, rather than the specific content and validity of an argument as determined using *Toulmin's* approach.

Figure 53 describes the types of student argumentation that occurred in response to Mr. Field's teaching strategies, especially the strategies of *Claim-Evidence Approach* (CLEA) and *Daily Science*. Student argumentation during *Daily Science* consisted of Mr. Field's questions, students' one-word answers, and Mr. Field's evaluation. Since the purpose of implementing *Daily Science* was to provide students the opportunity to practice discussing science, the nature of the classroom discourse was simple and not highly structured. Student argumentation during *Daily Science* stayed within the first level of argumentation (1) as seen in Figure 53.

On the other hand, the more complex student argumentation that occurred during CLEA consisted of Mr. Field's questions, students' answers, and Mr. Field's evaluation without closing the discussion; then it included Mr. Field's addition of more questions or prompts, students' justification, Mr. Field's explanation based on students' justification, and finally Mr. Field's more extended argumentation. The nature of the classroom discourse during CLEA moved into the more complex levels of argumentation (levels 2, 3, and 4) depending on Mr. Field's interaction with students.

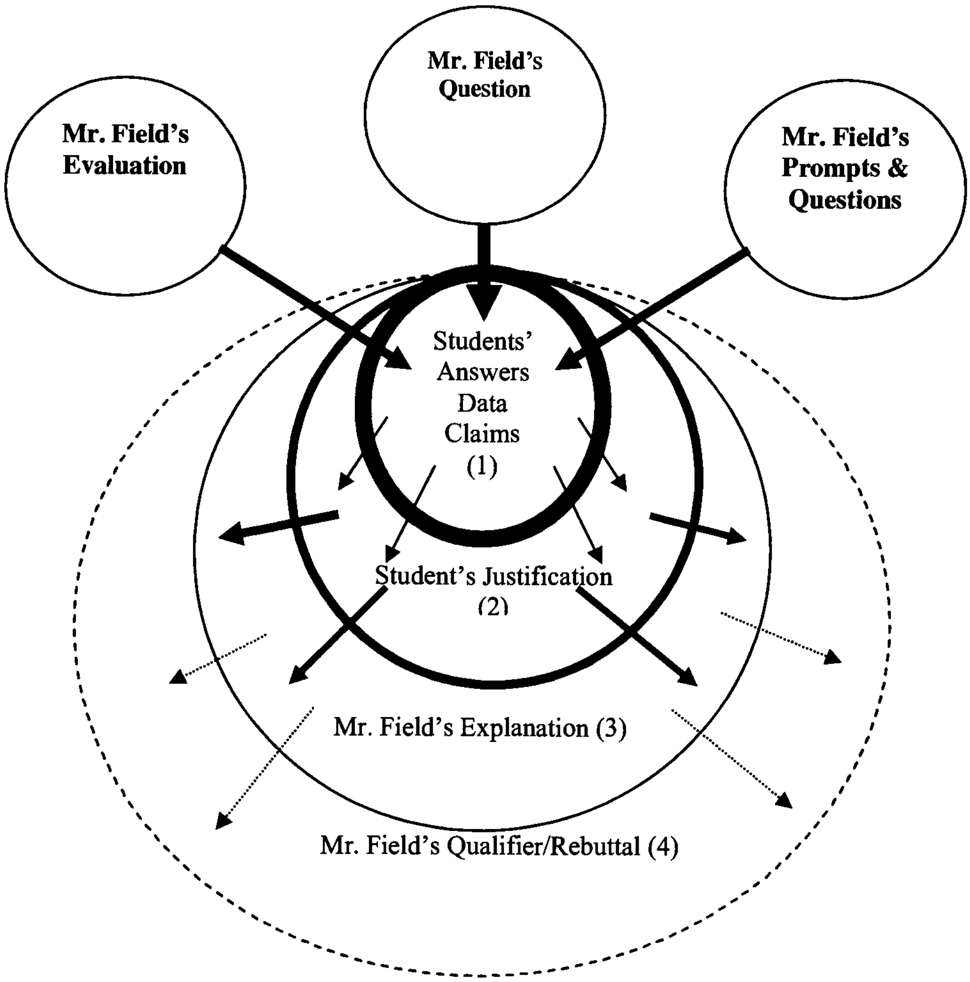


Figure 53: Student argumentation in response to Daily Science and CLEA

Both opportunities for argumentation and the quality of student argumentation in the classroom were found to depend on various conditions. First, specifically designed teaching strategies, *Daily Science* and CLEA, provided students with increased opportunity to develop scientific arguments. Second, the quality of student argumentation during *Daily Science* consisted of less extended arguments by students, whereas student argumentation during CLEA consisted of more extended arguments as a result of the teacher interacting more with the students.

Third, students generally developed the arguments coded as *Data* and *Claim*. *Data* arguments (from *Toulmin*) were developed through examples from students' prior knowledge or experience in the form of an *Appeal to the instance* operation (*Epistemic Operations*) and the *Elaboration* reasoning skill (*Reasoning Complexity*). *Claims* were developed through application of knowledge in a different context in the form of an *Induction* operation and *Generativity* reasoning skill. Sometimes, *Warrants* were developed through the *Causality* operation and the *Justification* reasoning skill.

Fourth, Mr. Field provided arguments in the form of *Qualifiers, Rebuttals,* and *Backing*. *Qualifiers* (*Toulmin*) were possible through *Consistency* with other knowledge or experience (*Epistemic Operations*) and *Explanation* reasoning skills based on students' ideas (*Reasoning Complexity*). *Rebuttal* and *Backing* were sometimes developed by Mr. Field when he combined arguments to explain the mechanism of a phenomenon at the end of a discussion, or when he provided content about general principles or laws of science at the beginning of a lesson. Fifth, student written argumentation was found to vary in quality according to how well the students used scientific knowledge. Students' ability to use scientific argumentation was related to their academic achievement levels in writing and reading.

CHAPTER V

DISCUSSION AND IMPLICATIONS

Introduction

This chapter elaborates on the findings reported in Chapter IV and situates these findings within the context of previous research on science teaching and learning, with an emphasis on the literature related to scientific argumentation. This discussion will be presented in four sections that deal with how to promote students' use of scientific argumentation. The first section examines the relationship between scientific argumentation and the acquisition of scientific knowledge. The second section examines the relationship between scientific argumentation and the teacher's involvement. The third section discusses how students' scientific thinking skills are developed through explicit teaching practices to promote scientific argumentation. The fourth section discusses the usefulness of the analytic tools in this study to understand the process of developing scientific argumentation.

The Relationship between Scientific Argumentation and Scientific Knowledge

Young learners formulate goals and processes to solve problems arising in the context of everyday life, whereas scientists formulate them differently in the context of science (Kuhn, 1992; Reif & Larkin, 1991). However, problems arise when students use their knowledge of everyday life to carry out scientific experiments, in which they must call on scientific knowledge to find evidence and form conclusions.

Mr. Field believes that students need to broaden their scientific knowledge before engaging in scientific experimentation in the classroom. To help students develop their background knowledge of science, Mr. Field used the *Claim-Evidence Approach* as a teaching strategy by guiding students through the textbook, demonstrating simple activities, and showing students how new scientific terms are needed to express new ideas.

When Mr. Field instructed students on how to express their understanding through writing, he emphasized the use of the scientific terms. He supported their argumentation skills giving them a writing template to describe (a) what they thought would happen, (b) what actually happened, and (c) why it happened based on their observation and experimentation. The products of student written argumentation in lab reports varied in their quality of argumentation, and Mr. Field counted the number of new scientific terms being used as one of the scoring criteria. However, students' ability to ascribe those scientific terms to particular situations was also an influential factor on the quality of students' argumentation. That is, Mr. Field scored students' lab reports in relation to how many scientific terms students used and how they applied them for the purpose of explaining the mechanism of the situation. Von Aufschnaiter et al. (2005) found that argumentation has an important function in elaborating students' understanding of science. As students can only argue about what they already know, it is the content-specific knowledge, or lack thereof, acquired from students' previous experience that restricts students' argumentation. Here are some examples of written argumentation from this study that differed in quality according to the students' ability to apply the rules of the scientific domain, not of everyday life.

One student used new scientific terms (underlined in this claim from the **Complete** lab report) to predict what would happen and why if he pushed the balloon with the use of the straw nozzle.

> I think that the balloon with a nozzle of 35 cm will stay in the air the longest. I think this because there is the same volume of air in the actual balloons, but there is a greater volume of air in the longer nozzles. The air in the rockets is under pressure causing it to flow out of the object at a certain speed. As long as the air is flowing out of the rocket, it can defy the force of gravity. Since the rocket with a nozzle of 35 cm has the greater air volume, it can defy gravity the longest

Here, the student used four new scientific terms to demonstrate knowledge gained through reading the textbook and interacting with Mr. Field. Furthermore, it is understandable that this student chose certain terms, such as volume or gravity, to describe the mechanism of the phenomenon. In this **Complete** lab report, the student described why the longest nozzle, 35 cm, worked as the most powerful tool for keeping the balloon in the air the longest. The longer the nozzle is, the more air volume there is. More air volume defies gravity more strongly, which makes it possible for the balloon with the longest nozzle to stay in the air longest.

The example from the **Limited** lab report included *Warrant* and *Data*, supporting the student's own claim to answer the question, *What length of nozzle makes the balloon stay longest in the air?* However, even though this student provided a few new scientific terms, her explanations of how the rocket balloon hovered the longest only consisted of scientific terms without any meaningful argument to show how each scientific term was chosen to explain this phenomenon. This student used incomplete sentences to describe the mechanism of the phenomenon. This student was a low achiever in writing and reading. This example proved that this student was supposed to use scientific terms that he learned during CLEA in his writing, but he did not appropriate scientific knowledge to use those terms to support his prediction.

> I now it would be the middle because of the <u>force</u> it has and <u>energy.</u> It has to <u>acceleration</u> can be a good and bad thing because it could matter of <u>distance</u> of <u>direction ,</u> the <u>mass</u> of object and so we <u>time</u>s it could matter be time and the <u>reference point</u> to determine the distances of the flight

Overall, Mr. Field believed that students' ability to develop argumentation depended on their scientific knowledge. Mr. Field added that students do better in developing argumentation at the end of the academic year after they acquire more scientific knowledge.

Based on the relationship between scientific argumentation skills and the use of scientific knowledge, it is necessary to teach students to practice scientific argumentation within a particular scientific knowledge context. This situating of argumentation as a core element in the learning of science has two goals. One is to engage students in the coordination of conceptual and epistemic goals. The other is to make students' scientific thinking and reasoning visible so that the teacher can do formative assessment (Osborne, Erduran, & Simon, 2004).

It is also suggested by Kuhn (1992) that it is important to provide a concrete science context where students can demonstrate their scientific thinking skills through scientific argumentation. The results of this study also support the research on how students' scientific knowledge is related to their development of scientific argumentation in that (a) higher academically achieving students (based on reading and writing scores of state tests) provided more structured and extensive arguments in their written lab reports; (b) lower academically achieving students provided unstructured and less extensive arguments in their lab reports; and (c) Mr. Field believed that students would be able to develop scientific arguments at the end of the seventh-grade academic year as they acquire more scientific knowledge.

The Relationship between Students' Scientific Argumentation and the Teacher's Involvement

Students' argumentation opportunities were promoted when Mr. Field engaged in guiding students to extend their knowledge or skills by prompting, questioning, and giving clues. In Chapter IV, two different types of argumentation emerged (a) *fundamental argumentation,* consisting of Mr. Field's initial questions, students' responses to Mr. Field, and Mr. Field's evaluation; and (b) *exploring argumentation,* when Mr. Field provided extended knowledge and supported more complex skills.

In *fundamental argumentation*, there is a linear pattern of discourse consisting of a two-part question-answer structure or a three-part question-answer-evaluation structure, called "Triadic Dialogue" (Lemke, 1990). *Fundamental argumentation* uses the linear flow as diagrammed in Figure 54.

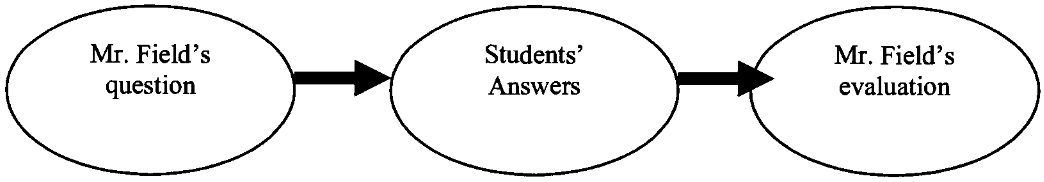


Figure 54: Fundamental Argumentation

In *exploring argumentation,* there is a circular pattern of discourse rather than a linear one (Figure 55). Mr. Field created a question, students answered it, Mr. Field evaluated their answers with more questions or prompts, and students developed extended argumentation in response to Mr. Field's instruction. Mr. Field then synthesized all content based on students' ideas. The students often developed a higher quality of argument by offering alternative or contrasting points of view. This mutual interaction between the teacher and students takes place as a circular argument, *exploring argumentation*, represented in Figure 55.

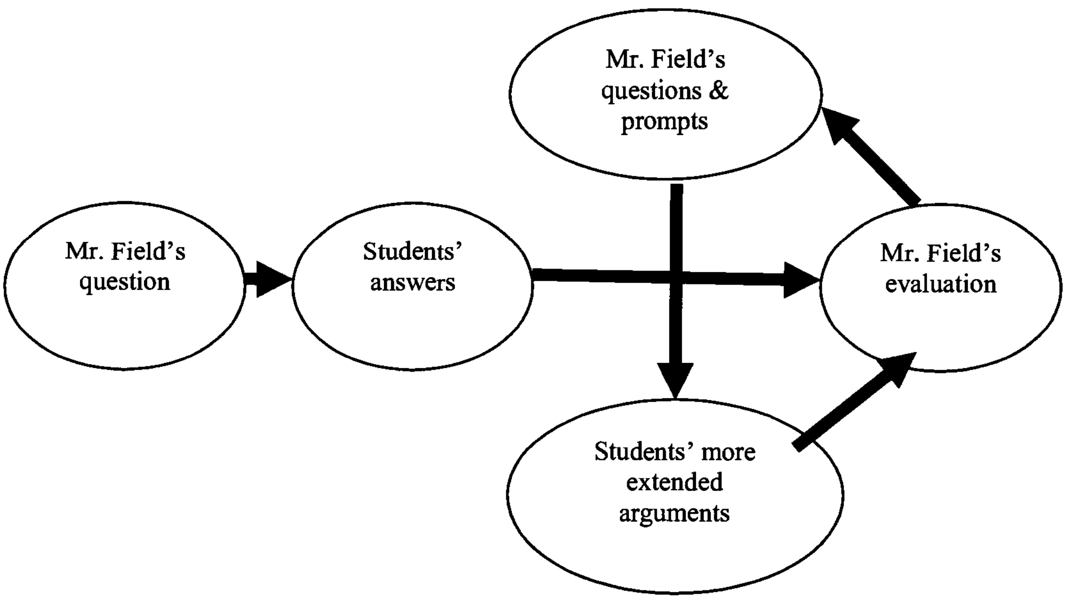


Figure 55: Exploring Argumentation

The teacher's involvement in students' development of argumentation skills was critical in shifting from *fundamental* to *exploring* forms of argumentation. For example, Mr. Field provided a concrete demonstration, such as dropping a golf ball and a ping-pong ball, to provide students a base from which to reason. Mr. Field continued by reasoning out loud that gravity is constant. When students provided evidence refuting the claim that gravity is constant, Mr. Field introduced a new concept of "resistance" to explain the mechanism of the phenomenon. Mr. Field's demonstrations and prompts enabled students to apply their knowledge to achieve a higher quality of argumentation, making the argument shift from *fundamental* to *exploring*.

This process of developing *exploring* forms of argument is called "Reflective Discourse" by van Zee & Minstrell (1997). The teacher in their study played a role as a *helper* for students to enact identities as competent "sense makers," as an *elaborator* rather than evaluator to extend students' ideas, and as a *mentor* to foster and monitor the students' development of ideas of a higher quality. These three roles also occurred when Mr. Field interacted with students in the context of *exploring argumentation*, helping students develop extended forms of argument. Without Mr. Field's scaffolding roles as an elaborator or mentor using questioning or prompting, students could have not discussed the issue of gravity with two different theories, *gravity is constant* or *gravity depends on the weight of materials.*

These results regarding the relationship between scientific argumentation and the teacher's engagement are consistent with the results of Hogan, Nastasi, and Pressley (2000). The teacher's questions or prompts made it possible for students to expand

and clarify their own thinking to meet the goal of lessons. The teacher's questions and students' responses could be built up without the closure of an evaluation, leaving more interactions for students to synthesize and allowing them to explore the full potential of collective ideas. Finally, when the teachers knew students' individual reasoning abilities, there was more effective instruction, allowing students chances to reflect on their learning while constructing new knowledge. In this study, one of Mr. Field's explicit teaching strategies, *Daily Science*, included scaffolding to help students express alternative ideas in designing an investigation. At the beginning and end of the *Claim-Evidence Approach*, Mr. Field also scaffolded students to express contrasting arguments and claims and to discuss the limitation of experiments.

When Mr. Field was interviewed, he discussed his understanding of scientific argumentation. Mr. Field differentiated hands-on activity from scientific inquiry, in that in scientific inquiry, students have chances to develop the abilities to use evidence collected from experiments and to develop and support their own claims. Therefore, it can be concluded that Mr. Field's appropriate understanding of developing scientific thinking skills through argumentation enabled him to scaffold students to develop more extensive arguments using explicit teaching strategies. This showed the consistent relationship between his understanding and practices of scientific argumentation in the classroom.

The teachers in the studies by van Zee & Minstrell (1997) and Yerrick (2000) interacted with students as both researchers and participants in order to foster students' abilities to develop reasoning through argumentation. The participating teachers, as researchers, understood what scientific argumentation is, how important it is, and how they could help students develop argumentation through teacher-designed instruction. These teachers' understanding of scientific argumentation led them to play roles including: (a) helping students propose their own claims by providing background information, (b) allowing students' ideas to be tested without evaluating them, and (c) creating a context to foster and monitor students' ideas through their argumentation. The consistent relationship between the teachers' understanding of and teaching practices regarding scientific argumentation created more structured and extended opportunities for student argumentation, such as through teachers' use of prompts and questions.

It is implied that students could have more of a chance to develop a higher quality of argumentation with more teacher involvement and interaction with students. It is clear that teacher involvement in students' expression of scientific argumentation improved the quality of argumentation. That is, the teacher's active engagement guided students to a higher quality of argumentation by shifting the form of argument from *fundamental argumentation* to *exploring argumentation*. In this study, students were able to justify their claims with the use of evidence through Mr. Field's use of extended content and demonstrations in his role as a mentor and a facilitator.

The Effectiveness of Explicit Teaching Strategies for the Practice of Scientific Argumentation

Teaching strategies targeting specific skills provided students with opportunities to develop skills in argumentation. Through the *Claim-Evidence Approach*, Mr. Field instructed students to develop their own claims to be tested at the beginning of the strategy, *Framing the Investigation*. Students also had chances to reflect on their predictions about what would happen, as well as on what actually happened, why it happened, what limitations in designing the investigation there were, and how the experiment could be designed more effectively. For this process of reflective assessment, Mr. Field used the template of the *Inquiry Guideline* to scaffold students to practice developing written argumentation. Students had a chance to write their own *claims* to be tested, *evidence* to support their claims, *justification* to connect the evidence with claims, and *rebuttals* as refuting evidence in the investigation. Toth, Suthers, and Lesgold (2002) and White and Frederiksen (1998) also reported the effectiveness of using explicit assessment models for students to reflect on the reasoning skills involved in scientific inquiry. This explicit reflective assessment provided students with opportunities to think about how their experimental questions were framed, what variables were selected, how the data were collected, how hypotheses were supported or refuted by data, and how new hypotheses were developed from other experiments in the context of community with peers in groups or teachers in a whole class discussion.

Reif and Larkin (1991), Klahr and Dunbar (1988), Kuhn (1989a), and Chinn and Brewer (1993) reported that young learners use undeveloped reasoning skills to solve scientific problems. However, students are expected to develop their scientific thinking through the practice of argumentation with the support of instructional scaffolding, such as prompting, questioning, and monitoring the development of ideas. Osborne, Erduran, and Simon (2004) also suggested that developing the ability to argue effectively is a long-term process, requiring recurrent opportunities to practice throughout the curriculum. The main message in this study is that it is possible to prompt students to use scientific argumentation if it is explicitly addressed and taught.

This study shows that it is important for the teacher to provide chances, through explicit teaching practices or curriculum, for students to practice developing claims, collecting data, differentiating evidence from data, using evidence to support their claims, and using other evidence to refute other claims. In this study, Mr. Field taught students what a claim was and how they could develop their own claims for the experiments. He also enabled students to retrieve their prior scientific knowledge as background information to support their evidence and to justify the mechanism of the phenomenon being studied.

At this moment, "wait time" is still an issue. In some cases, Mr. Field did not provide enough time for students to think of what evidence they had to use and how they could develop the relationship between the evidence and their claims. Instead, he instantly provided the missing elements of the argument based on students' initial attempts. Teaching students about argumentation requires allowing students "enough" time to retrieve the content about which they intend to argue (von Aufschnaiter et al., 2005). Thus, teachers need to foster a learning environment that enables students to explore science content systematically in order to familiarize themselves with relevant data. While Mr. Field often provided limited wait time in classroom discourse, other explicit teaching strategies allowed students the time to become familiar with the specific content such as Newton's laws or with new scientific terms, which in turn were used to develop their claims and to predict what would happen and why.

Mr. Field created an environment where students were exposed to two conflicting theories, which led them to a better understanding of their data and led to the development of more refined claims or justification. For example, Mr. Field gave time for a discussion on two conflicting theories of gravity, which enabled students over time to develop arguments that they would not have been capable of without Mr. Field's scaffolded instruction.

Therefore, practical and explicit teaching strategies, including providing time to learn the targeted science content and creating an authentic learning environment through a teacher's scaffolding, are seen to be one of the most effective and critical factors for strengthening students' abilities to develop argumentation.

The Toulmin, Epistemic Operation, and Reasoning Complexity Approaches for the Process of Argumentation

Three different dimensions—*Toulmin, Epistemic Operation*, and *Reasoning Complexity*—were employed in this study to analyze Mr. Field's and his students' discourse and to examine how they interacted using scientific argumentation. This study aimed to characterize the dynamic processes of creating opportunities for argumentation in a whole class discussion, using Mr. Field's teaching strategies. *Toulmin*'s analysis was used only to analyze the structure of arguments in students' discourse.

Osborne, Erduran, and Simon (2004) illustrated that situating argumentation as a central element in the learning of science has two functions: one is as a heuristic to engage learners in the coordination of conceptual and epistemic goals, and the other is to make student scientific thinking and reasoning visible to enable formative assessment by teachers or instructors (p. 995). In this study, the former function can be analyzed by *Toulmin*'s approach and by *Epistemic Operation*, and the latter function can be analyzed by *Reasoning Complexity*. Individual argumentation can be different from interpersonal argumentation in the social context. Individual argumentation, such as written argumentation, is defined as the ability to coordinate evidence and theory in order to support or refute an explanatory conclusion; it can be analyzed using *Toulmin*'s approach only. However, interpersonal argumentation, which is formed during small group discussion or whole class discussion between the teacher and students, cannot be analyzed using only *Toulmin*'s approach. Since there is mutual interaction between the teacher and students (or among students) that in turn influences consecutive arguments, it is necessary to analyze interpersonal discourse in the context of a social setting. Knowledge from peers or from the teacher that arises during the discussion could extend a learner's thinking skills toward developing argumentation.

Students who developed argumentation skills in the social setting could not have done so without the presence of Mr. Field's or the other students' argumentation. For example, when students discussed limitations of the rocket balloon experiment at the end of the activity, Mr. Field initiated a discussion of gravity as one of the limitations. As a result of Mr. Field's reminding students of the content about gravity, students discussed two conflicting theories within the authentic inquiry environment created by Mr. Field. Mr. Field initiated the discussion by asking what force was responsible for pulling the rocket balloon down and preventing it from hovering in the air. When one student named it "gravity," Mr. Field asked that student to define it. On the basis of this definition, Mr. Field asked his students if gravity is constant or dependent on mass; he then gave a simple demonstration by dropping two objects with different masses. Then, there was a brief discussion between two groups that supported opposing theories: one that gravity is constant and the other that gravity is dependent on mass. The interaction between Mr. Field and his students, including Mr. Field's demonstrations of the two falling objects and the students' predictions about the results, elicited a more active discussion about the two conflicting theories.

Students' argumentation that developed in the social context from Mr. Field's prompts, questions, and demonstrations provides a model for promoting better argumentation. Encouraging students to externalize their thinking can lead to the development of argument skills, which involve the public exercise of reason. This externalization requires a shift from the intra-personal plane of rhetorical argument to the inter-personal plane of dialogical argument. Rhetorical argument can be examined with *Toulmin's approach,* and dialogical argument can be examined using the *Epistemic Operation* approach. The complexity of developing arguments in a social setting requires the two analytical approaches for a more complete interpretation.

The written argumentation in this study was analyzed using Toulmin's method, since students reasoned intra-personally regarding what their claims were, what evidence they found, and how that evidence supported their claims. The other two analyses, *Epistemic Operation* and *Reasoning Complexity*, which were identified and formed in the social context of discussion, are not as meaningful for the analysis of written argumentation.

These three analysis tools, *Toulmin, Epistemic Operation,* and *Reasoning Complexity*, could be modified by teachers and science educators in order to reflect on teaching strategies to promote student argumentation. The Scientific Argumentation Table (SAT) in this study included both the teacher's and students' discourse, and these three analysis tools could be used in conjunction with the SAT to help teachers and science educators examine such questions as: How does student argumentation vary in quality? How does the teacher encourage students to retrieve more knowledge in developing argumentation skills? The analyses using the three tools applied to this study could enable teachers to reflect on their teaching practices on scientific argumentation and to develop their teaching strategies or formative assessment to develop the highest quality of argumentation. For example, with *Toulmin*'s approach, if the science teacher or educator finds more *Warrants* developed by the teacher rather than by students themselves, providing students with opportunities to develop more *Warrants* can be critical in designing the new instruction and curriculum for argumentation.

Limitation of the Study

All research involves an intricate balance between project goals and practical considerations. Resultant compromises constitute limitations that should be considered when interpreting and applying the results for the investigation. This study is no exception. Compromise due to such factors as limited time, availability of subjects, and other methodological limitations necessarily mitigates the interpretation and generalizability of the project results. The following limitations are found in this study.

First, regarding the nature of participants, Mr. Field and his students are one of the limitations in this study. Mr. Field was selected by purposive sampling method as the one most informative subject based on his understanding of scientific argumentation. The researcher in this study worked with Mr. Field for the last three years in a summer professional development program. He then showed interest in developing teaching strategies about scientific inquiry with a focus on students' chances to reflect on their learning of science as inquiry. Mr. Field was selected not because he is veteran in, but because he has been and is interested in designing and implementing teaching strategies about scientific argumentation as well as scientific inquiry.

In addition, there was the limitation in observing lessons in this study. Even though the lessons included group work at tables, Mr. Field did not give enough discussion time for students. Mr. Field did not give enough time for students to extend their knowledge in answer to his questions, but instead sometimes provided explanations or descriptions right after asking a question. The nature of the students also worked as one of the study's limitations, since some students in a group had a tendency not to produce informative discourse. One of four students in the third period was given instruction by the researcher to be more talkative and informative in discussing the topics. However, the students in a group who were asked to participate more seemed to be informative at first, but they stayed too quiet for the researcher to collect the data for the group work.

Second, the validity of data analysis is another limitation. Out of 60 sample lessons, 23 were analyzed. The differing time and place that the lessons were analyzed in influenced the validity and reliability of the data analysis to some degree. At the beginning of the data analysis, it took a lot of time to become familiar with the coding system of the three analysis tools. Once the researcher became familiar with the coding, she was able to remove bias in the data analysis to insure its validity; then the researcher repeated the analysis with the same coding system in the earlier data. During the middle part of the data analysis, the researcher developed coding agreement with another knowledgeable researcher, insuring that the findings of this study based on this data analysis were valid with respect to the research questions. Subsequent investigation and refinement will be likely to improve the validity of these instruments in their data analysis.

Finally, the researcher may also be viewed as a limitation in this study. As the principal instrument of data analysis, it is unavoidable that at least some components of the researcher's experience, beliefs, and biases influence the results and their interpretation. Certainly, the researcher's commitment to scientific argumentation guided the direction of this study. For example, the conversations between Mr. Field and the researcher could have influenced his teaching for scientific argumentation. In the middle of this investigation, Mr. Field was asked by the researcher to provide students with more time to discuss in groups after each issue, to better meet the goal of this study. However, there were not enough data on argumentation in groups to collect and analyze, so any argumentation that occurred in groups in this study was excluded. Right after the researcher's brief intervention, Mr. Field seemed to provide more time for students to discuss issues during *Daily Science* and the steps of inquiry during the *Claim-Evidence Approach.* However, in subsequent lessons, he resorted to his original teaching pattern and did not continue to provide students enough time to discuss in groups.

Implication for Future Study

At the heart of this study are the practical questions of how to promote student argumentation in the classroom. The results of this study support the idea that Mr. Field, as a science teacher, displayed an understanding of scientific argumentation and implemented teaching strategies that promoted students' abilities to develop scientific argumentation. In response to those teaching strategies, student argumentation was observed to shift from *fundamental argumentation* to *exploring argumentation* prompted by Mr. Field's scaffolding.

On the basis of these findings, research questions for future study can be addressed. How does teachers' knowledge about scientific argumentation relate to their teaching strategies to promote student argumentation? How does students' argumentation differ in response to those teachers' teaching strategies? Is student argumentation more extended through interaction with a teacher who understands it better? How does student argumentation differ in its quality in groups with or without the teacher? How do teachers' roles of scaffolding differ between teaching strategies to create students' opportunities for argumentation? How do students' different roles in groups influence their abilities in developing scientific argumentation? How much do preservice teachers understand about scientific argumentation? What kind of teaching strategies do preservice teachers implement to promote student argumentation? What kind of barriers prevent students from developing scientific argumentation and how do teachers deal with those barriers?

The four implications in this study are: (a) that teaching science in a social constructivist curriculum provides discourse opportunities that can support student argumentation skills, (b) that effective student argumentation is situated in specific science content, (c) that research methodologies need to be designed for analyzing scientific argumentation in specific settings, and (d) that teacher professional development can significantly impact instructional strategies for teaching scientific argumentation.

First, teaching science in a social constructivist curriculum provides discourse opportunities that can support student argumentation skills. The interactions between the teacher and students were embedded within a certain context, and the teacher provided students with opportunities to extend their knowledge and skills to learn science as argumentation as well as inquiry. The teacher in this study, Mr. Field, emphasized the social setting in working as a whole class or in small groups, through which students should gain understanding of the nature of scientific inquiry and the nature of scientific knowledge. Mr. Field's interactions with the students were tied to this setting, namely to his goal of providing students with the experience of framing their own research questions, designing an investigation after gaining understanding of the independent and the dependent variables, and analyzing and interpreting their data through interaction with others. At this time, students could develop their claim, differentiate the independent variable from the dependent and the evidence from the data, find the pattern in the data, and discover the limitation of the experiment in each lab activity. Under the *Inquiry Guideline*, students came to understand how they develop different opinions from the same observation or result and how they negotiate those opinions in order to come to consensus, by supporting their stance or refuting it with other collected data.

This investigation provided an understanding of the nature of low to average achieving students' scientific argumentation and the nature of the teacher's roles of scaffolding (Hogan, Nastasi, & Pressley, 2000). The identification of a more complex argumentative structure reveals how different interaction modes and argumentative styles can occur in different social contexts. Within this issue, it may be possible to verify the "change" or "evolution" in students' abilities to develop skills in scientific argumentation as an effect of the interaction with the teacher and peers in a guided or scaffolded learning environment (Pontecorvo & Girardet, 1993).

The second implication is that effective student argumentation is situated in specific science content. Actually, this study investigated how the teacher provided students with opportunities to develop scientific argumentation and how the students responded to teaching strategies directed at the process of argumentation. As students could only develop arguments based on what they already knew, the lack of scientific content knowledge was a major factor restricting students' abilities in developing advanced skills in argumentation. Surely, the teacher's scaffolding was also critical for creating students' opportunities to develop scientific argumentation skills. The research exploring the nature of the interrelationship between students' cognitive understanding of science and their opportunities for scientific argumentation will address the passage from the interpsychological in the social context to the intra-psychological or individual level in the cognitive context (Resnick et al., 1993). Understanding the relationship between students' cognitive development and their opportunities for advanced scientific argumentation could enable further research to construct another relationship between students' achieving levels in academics and their skills in scientific argumentation. What kind of influence do students' academic achieving levels have on their abilities to develop scientific argumentation? How do lower and higher achieving students interact and help each other develop argumentation?

The third implication is that research methodologies need to be designed for analyzing scientific argumentation in specific settings. Three different analysis tools for scientific argumentation were employed to analyze the Scientific Argumentation Tables or SATs. These SATs showed how the teacher interacted with the students; that is, who contributed more to the discussion, who provided simple arguments or complex ones, how and with what questions the teacher helped students develop argumentation, and how students responded to the teacher's inputs or questions qualitatively.

In addition, each component of the three analysis tools was counted each time it appeared in the discourse, which gave percentages of each component's usage and displayed quantitatively which components were used more or less frequently. The quantitatively analyzed frequency of the components' usage could be related to the quality of the arguments in the SATs that occurred in the context of whole class discussion or group work. For example, if *Toulmin*'s analysis displayed that the components *Data* and *Claim* were used more frequently than the others, this means that the teacher uses more questions requesting conceptual knowledge. If *Toulmin*'s approach shows more *Warrants, Qualifiers,* and *Rebuttals*, this means that the teacher asks more questions requesting procedural knowledge. Looking at these contrasting instructional contexts in light of the amount of argument that occurs in them could shed light on the factors that influence the quality of reasoning skills displayed in conversational arguments, which could enable teachers or science educators to model and support the development of desired reasoning patterns. For example, certain types of questions or prompts can be found and developed as a guideline for teaching strategies, so that teachers could employ them to scaffold students to develop more extensive arguments, shifting from *fundamental argumentation* to *exploring argumentation*.

The investigation of argumentation occurring in contrasting contexts can take place in different forms. The argumentation in group work with and without the teacher is one of the contrasting contexts (Hogan, Nastasi, & Pressley, 2000). The argumentation with the teacher, in the teacher-centered and student-centered classroom, is another contrasting context (Watson, Swain, & McRobbie, 2004). The argumentation in group work versus whole class discussion is another one (van Zee & Minstrell, 1997). The argumentation in groups with different types of leaders, *inclusive, persuasive,* or *alienating*, would be also another contrasting context (Richmond & Striley, 1996). In all of these contexts, three different argument analysis tools can be employed to understand the nature of scientific argumentation.

The OTOP, the observational protocols designed by OCEPT used in this study, can be employed to show the profile of teaching strategies used for developing scientific argumentation. This OTOP tool can be used as one of the ways to reflect upon the teachers' teaching strategies, providing analysis of how often students are encouraged to express their different ideas and how the teacher challenges the students to support their stance with others, using arguments. For example, the OTOP profile of teaching strategies by exemplary teachers and beginning teachers would be different for item #4 (challenging ideas), #6 (conceptual thinking), or #7 (divergent thinking), items which are related to the teachers' providing students with opportunities to develop scientific arguments and to students' responses to those teaching strategies. The comparable investigation of how the exemplary teachers help students develop scientific argumentation would be used as a guide for how to teach scientific argumentation in a teacher preparation program for preservice teachers and in an induction program for beginning teachers.

The fourth implication is that teacher professional development can significantly impact instructional strategies for teaching scientific argumentation. A teacher preparation program for preservice teachers and an induction program for beginning teachers should include opportunities for teachers to reflect on their knowledge or understanding of scientific argumentation and to develop inquiry work-samples. The teacher, Mr. Field, stated that understanding of scientific argumentation was helpful in selecting and designing instructional strategies in which students could have chances to approach inquiry in a holistic way. That is, students framed and designed the investigation and then collected and interpreted the data. During this inquiry process, students were guided by the teacher, Mr. Field, to develop their arguments, including *Claims, Data, and Warrant.*

In addition, in the case of preservice teachers, with whom the researcher worked in another project, there was a display of well-developed understanding of scientific inquiry. However, these teachers did not differentiate scientific inquiry from hands-on activities in terms of advanced reasoning skills. These preservice teachers did not know the term "argumentation" at all, but they understood it as students' abilities to apply knowledge in a new context. Therefore, it is very essential for preservice and beginning teachers to have opportunities to reflect on their knowledge about scientific argumentation as well as scientific inquiry through a professional development program. For instance, explicit discussion of the learning objectives in scientific inquiry and the assessment standards or criteria, such as those Mr. Field used with his students in this study, is also a desirable feature. Since the research says that preservice and beginning teachers' knowledge or understanding of teaching and learning science is unpredictable, it is very critical for them to have the opportunity to reflect on and develop firm and structured understanding of these concepts.

Then, based on preservice and beginning teachers' understanding of scientific argumentation, it is useful to compare their teaching strategies with those of exemplary teachers, in light of providing more opportunities for developing scientific argumentation. Finally, this investigation into the knowledge and teaching strategies regarding scientific argumentation is also useful in finding a consistent or inconsistent relationship between them.

The rationale for science reform is based on the idea that students need to develop the ability to solve social and scientific problems arising in modern times, which is called "scientific literacy." To reach this goal of scientific literacy in schools, students need to have opportunities to develop abilities in argumentation, such as how to support their stance or refute others' using their own evidence. It is essential to understand the nature of teachers' teaching strategies and students' argumentation in natural settings in the classroom context, because we know that practicing scientific argumentation is critical to understanding how scientific knowledge is constructed. The understanding of scientific argumentation gained by teachers and students through their interactions make science education an education in reasoning and critical thinking. I, as the researcher, hope this study will offer a small contribution toward such a goal in science education.

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APPENDIX A

Initial Query

Dear ____________

My name is Young-Shin Park and I am a doctoral student in the department of science and math education at Oregon State University. I am beginning my dissertation research soon and am asking you to participate in my investigation.

My research project will focus on science teachers' explicit teaching strategies to promote opportunities for students to demonstrate reasoning skills in the context of scientific inquiry. My research consists of two parts. In the first part, I will work 7-8 science teachers from the levels of upper elementary to those of secondary. In the second part, I will work only teacher finalized from the previous part of research. Right now, I am contacting you for the first part of my research.

For the purpose of my study, I will ask you to have one-time interview with semi-structured protocols first to see how you understand scientific inquiry in terms of argumentation and how you implement scientific argumentation. You can choose any time and date when you feel free for your interview. This interview can take place at your school site during the summer. Generally, I will ask how you define scientific inquiry in your classroom, how your scientific inquiry will differ from those of scientists, how hands-on activities can differ from scientific inquiry activities, how you provide students with opportunities of scientific thinking, if you have any critical example of successful scientific argumentation for students' reasoning skills, and finally what kind of barriers you encounter during your teaching scientific inquiry. All interviews will be audiotaped during August and September 2004.

Then, I will ask you to choose one lesson so that I can observe how you implement students' scientific argumentation opportunities on-site. During observation, I will take down some fieldnotes and use the observational instrument developed by OCEPT (Oregon Collaborative for Excellence in the Preparation of Teachers) research team in Oregon, which is called OTOP (OCEPT-Teacher Observation Protocol). I am focusing on your teaching strategies only, NOT students' responses to your teaching at this time. I might use videotaping your teaching. This will happen during September or October 2004. This observation will make me compare your knowledge through interview with teaching practices through observations.

Confidentiality will be maintained through the use of coding, rather than names, on interview, class observation, and fieldnotes. Additionally, these data sources will be kept in a locked location at all times and be available only to my major professor and me. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants. Please note that your participation in this research is voluntary and you may withdrawal from the investigation at any time without consequences.

The information that you will provide through your participation in this project is extremely valuable to my research. I would like to thank you in advance for your consideration.

Please contact me at parky@onid.orst.edu or (541) 737-1824, to indicate your interest in participating in this study or for further information. Please indicate if you are also willing to open your classroom to the once observation of this study during September 2004.

You may also contact my major professor, Larry Flick (flickl@onid.orst.edu; 541-737-3664). If you have questions about your rights as a research participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator at IRB@oregonstate.edu (Tel: 541-737-3437).

I look forward to working with you.
Sincerely,
Young-Shin Park

APPENDIX B

INFORMED CONSENT DOCUMENT

Project Title: Analyzing Teachers' Explicit Teaching Strategies and Students' Discourse In the Context of Scientific Argumentation
Principal Investigator: Larry Flick/Department of Science and Mathematics Education
Research Staff: Young-Shin Park

This is a research study. The purpose of this research study is to get the knowledge of how those teachers understand and implement scientific inquiry in terms of scientific argumentation in the classroom. For this investigation, 7-8 teachers will be contacted, interviewed once, and observed once and the results will be used for research related to my doctoral dissertation and for subsequent publication. The purpose of this consent form is to give you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, what you will be asked to do, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not. This process is called "informed consent." You will be given a copy of this form for your records.

We are inviting you to participate in this research study because you are one of teachers at the levels of upper elementary or secondary schools, where your students have abilities to understand and do scientific inquiry in some degrees, and you have shown your interests in implementing ideal scientific inquiry in the classroom through professional development program, " The Annual Oregon Science Teacher Leaders Institute" developed and run by Oregon Department of Education, Oregon Science Teacher Association, and Department of Science and Mathematics Education at Oregon State University, for the last few years.

If you agree to participate, your involvement will last 30-40 minutes for your interview to ask your knowledge about scientific inquiry in terms of scientific argumentation. Another involvement will also last approximate 1 hour for your class observation to analyze how you implement scientific inquiry in your classroom.

The following procedures are involved in this study. By initialing in the space provided, you verify that you have been told that audio/video recordings will be generated during the course of this study.

First of all, I will ask you to fill out the demographical information questionnaire at the beginning. Then, I will also ask you to have interview during August or September 2004 by meeting me at your school site. The interview will use semi-structured interview protocols aimed to probe your views related to scientific argumentation in the context of scientific inquiry and explicit teaching strategies to promote those opportunities for students to develop their scientific thinking skills during argumentation in the classroom. The interview will be done only once, lasting 30-40minutes and will be audio-taped.

Additionally, I will conduct class observation once to see how your knowledge of scientific argumentation is implemented through your explicit teaching strategies. The nature of these observations will depend on availability and class schedule of the teachers. You can choose any lesson, which you think includes most frequent opportunities for students to demonstrate their scientific thinking skills based on their observations and experimentations. The class observation time will last approximate 1-hour and be videotaped. Videotapes will record teachers' teaching strategies only by zooming camera focusing on teacher's bodies or faces and their voices only by using wireless microphone attached to teachers' bodies, not students' behaviors or voices. At this time, I will also use the observational instrument with field notes, OTOP (OCEPT-Teacher Observation Protocol) which includes observational protocols, developed by the OCEPT (Oregon Collaborative for Excellence in the Preparation of Teachers) research team in Oregon.

Confidentiality will be maintained through the use of codes, rather than names, on data sources (interview and observations with field notes). All data will be kept in a locked location at all times. The only people who will have access to the data will be my major professor and me. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants.

______________ Participant's initials

There are no foreseeable risks to participants in this project. This investigation will make a valuable contribution to science education by findings and developing some guide lines of explicit teaching strategies for science educators and science teachers to adopt to use in the classroom. In addition, teachers might have chances to reflect on their knowledge and teaching practices of implementing scientific argumentation for the ideal scientific inquiry envisioned by the *Standards* (NRC, 1996; 2000). Please note that your participation in this research is voluntary and you may withdraw from the investigation at any time.

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you want to skip or feel uncomfortable to answer any question through interview, you can do at any time. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled. Your data will be destroyed.

Questions are encouraged. If you have any questions about this research project, please contact: parky@onid.orst.edu (Tel: 541-737-1824) and my major professor, Dr. Larry Flick, at flickl@onid.orst.edu (Tel: 541-737-3664). If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed):

____

(Signature of Participant) (Date)

I have discussed the above points with the participant or, where appropriate, with the participant's legally authorized representative, using a translator when necessary. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

(Signature of Researcher) (Date)

APPENDIX C

OCEPT-Teacher Observation Protocol (O-TOP)
Outcomes Research Study - 2004

This instrument is to be completed following observation of classroom instruction. Prior to instruction, the observer will review planning for the lesson with the instructor. During the lesson, the observer will write an anecdotal narrative describing the lesson and then complete this instrument. Each of the ten items should be rated 'globally'; the descriptors are possible indicators, not a required 'check-off' list.

1. This lesson encouraged students to seek and value various modes of investigation or problem solving.
   (Focus: Habits of Mind)

   N/O 1 2 3 4

   Teacher/Instructor:
   - Presented open-ended questions
   - Encouraged discussion of alternative explanations
   - Presented inquiry opportunities for students
   - Provided alternative learning strategies

   Students:
   - Discussed problem-solving strategies
   - Posed questions and relevant means for investigating
   - Shared ideas about investigations

2. Teacher encouraged students to be reflective about their learning.
   (Focus: Metacognition – students' thinking about their own thinking)

   N/O 1 2 3 4

   Teacher/Instructor:
   - Encouraged students to explain their understanding of concepts
   - Encouraged students to explain in own words both what *and* how they learned
   - Routinely asked for student input and questions

   Students:
   - Discussed what they understood from the class *and* how they learned it
   - Identified anything unclear to them
   - Reflected on and evaluated their own progress toward understanding

3. Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.
   (Focus: Student discourse and collaboration)

   N/O 1 2 3 4

   Teacher/Instructor:
   - Organized students for group work
   - Interacted with small groups
   - Provided clear outcomes for group

   Students:
   - Worked collaboratively or cooperatively to accomplish work relevant to task
   - Exchanged ideas related to lesson with peers and teacher

4. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.
   (Focus: Rigorously challenged ideas)

   N/O 1 2 3 4

   Teacher/Instructor:
   - Encouraged input and challenged students' ideas
   - Was non-judgmental of student opinions
   - Solicited alternative explanations

   Students:
   - Provided evidence-based arguments
   - Listened critically to others' explanations
   - Discussed/Challenged others' explanations

5. The instructional strategies and activities probed students' existing knowledge and preconceptions.
   (Focus: Student preconceptions and misconceptions)

   N/O 1 2 3 4

   Teacher/Instructor:
   - Pre-assessed students for their thinking and knowledge

Helped students confront and/or build on their ideas
Refocused lesson based on student ideas to meet needs
Students:
Expressed ideas even when incorrect or different from the ideas of other students
Responded to the ideas of other students

6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals. (Focus: Conceptual thinking)	N/O	1	2	3	4

Teacher/Instructor:
Asked higher level questions
Encouraged students to extend concepts and skills
Related integral ideas to broader concepts
Students:
Asked and answered higher level questions
Related subordinate ideas to broader concept

7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. (Focus: Divergent thinking)	N/O	1	2	3	4

Teacher/Instructor:
Accepted multiple responses to problem-solving situations
Provided example evidence for student interpretation
Encouraged students to challenge the text as well as each other
Students:
Generated conjectures and alternate interpretations
Critiqued alternate solution strategies of teacher and peers

8. Appropriate connections were made between content and other curricular areas. (Focus: Interdisciplinary connections)	N/O	1	2	3	4

Teacher/Instructor:
Integrated content with other curricular areas
Applied content to real-world situations
Students:
Made connections with other content areas
Made connections between content and personal life

9. The teacher/instructor had a solid grasp of the subject matter content and how to teach it. (Focus: Pedagogical content knowledge)	N/O	1	2	3	4

Teacher/Instructor:
Presented information that was accurate and appropriate to student cognitive level
Selected strategies that made content understandable to students
Was able to field student questions in a way that encouraged more questions
Recognized students' ideas even when vaguely articulated
Students
Responded to instruction with ideas relevant to target content
Appeared to be engaged with lesson content

10. The teacher/instructor used a variety of means to represent concepts. (Focus: Multiple representations of concepts)	N/O	1	2	3	4

Teacher/Instructor:
Used multiple methods, strategies and teaching styles to explain a concept
Used various materials to foster student understanding (models, drawings, graphs, concrete materials, manipulatives, etc.)

APPENDIX D

INFORMED CONSENT DOCUMENT [teacher form]

Project Title: Analyzing Teachers' Explicit Teaching Strategies and Students' Discourse In the Context of Scientific Argumentation
Principal Investigator: Larry Flick/Department of Science and Mathematics Education
Student Researcher: Young-Shin Park

The purpose of this research study is to understand how you implement scientific inquiry in terms of scientific argumentation and how students develop their argumentation as responses to your teaching strategies. You have been invited to participate in further investigation through classroom observations. The results will be used for research related to my doctoral dissertation and for subsequent publication.

The purpose of this consent form is to give you the information to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, what you will be asked to do, the possible risks and benefits, your rights as a volunteer, and anything else about the research or this form that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not. This process is called "informed consent". You will be given a copy of this form for your records.

If you agree to participate, your involvement will last about 50 minutes for each lesson observed for one unit of content; up to 6 or 7 lessons. The class observations will be conducted to analyze how you promote students' reasoning skills through scientific argumentation in the context of scientific inquiry. During observations, you and your students will be audio- and video-taped.

The following procedures are involved in this study.
I will ask you to select one unit of content that might include scientific inquiry activities. We will discuss what instructional practices you will implement, what kind of lab activities you will implement, and what types of opportunities you will use for students' argumentation. I might attend a few lessons in advance to be used to your physical classroom context before collecting data. Then, I will talk about the goal of my research with your students and distribute *Informed Consent Document* for parents' permission and *Assent Document* for students' involvement in my research.

After getting the permission from students' parents, one video camera and a few audio recorders will be set up in the classroom to record students' practices and discourses as well as yours. Only one video camera and wide-voice capture recorder will be set up in the middle of classroom when you interact with students during whole class discussion or groups' presentations. Three voice recorders will be set up around the selected tables of students' groups to record their voice clearly when you interact with students during group activities. The groups of students will be selected depending on parents' permission and your criteria to rate students' levels. At each lesson, I will also use the observational tool with field notes, OTOP (OCEPT-Teacher Observation Protocol) developed by the OCEPT (Oregon Collaborative for Excellence in the Preparation of Teachers) research team in Oregon.

There are no foreseeable risks to you as a participant in this project. This investigation is intended to make a valuable contribution to science education by finding and developing some guide lines of explicit teaching strategies for science educators and science teachers to adopt to use in the classroom. You might have a chance to reflect on your knowledge and teaching practices of implementing scientific argumentation envisioned by the *Standards* (NRC, 1996; 2000).

You will not be compensated for your participation in this investigation.

Confidentiality will be maintained through the use of codes, rather than names, on data sources (interview and observations with field notes). All data will be kept in a locked location at all times. The only people who can access to the data will be my major professor and me. The collected data will be destroyed three years after the completion of this investigation. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants. By initialing in the space provided, you verify that you have been told that audio and video recordings will be generated during the course of this study.

_______________ Teacher's initials

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you decide not to take part in, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled. Your data will be destroyed.

Questions are encouraged. If you have any questions about this research project, please contact: parky@onid.orst.edu (Tel: 541-737-1824) and my major professor, Dr. Larry Flick, at flickl@onid.orst.edu (Tel: 541-737-3664). If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Teacher's Name (printed): ____

____ ____________________

(Signature of Teacher) (Date)

I have discussed the above points with the participant. It is my opinion that the participant understands the risks, benefits, and procedures involved with participation in this research study.

____ ____________________

(Signature of Researcher) (Date)

APPENDIX E

INFORMED CONSENT DOCUMENT [parent form]

Project Title: Analyzing Teachers' Explicit Teaching Strategies and Students' Discourse In the Context of Scientific Argumentation
Principal Investigator: Larry Flick/Department of Science and Mathematics Education
Student Researcher: Young-Shin Park

The purpose of this research study is to understand how teachers promote students' opportunities to develop their reasoning skills while they are developing scientific discourses with peers or teachers. For this investigation, your child's teacher, [NAME], has been invited to participate in this project through classroom observations of [TEACHER'S NAME] teaching techniques. The results of this investigation will be used for the student researcher's doctoral dissertation and for subsequent publication. The teacher, [NAME], as well as students in the classroom will be observed for approximately two weeks to meet the goal of this research.

The purpose of this consent form is to give you the information to help you decide whether your child can participate in this study or not. Please read the form carefully. You may ask any questions about the possible risks and benefits, your child's rights as a volunteer, or this form that is not clear. When all of your questions have been answered, you can decide if your child wants to be in this study or not. This process is called "informed consent". You will be given a copy of this form for your records.

Your child will be asked to provide his or her agreement to participate. If he or she agrees, he or she will be asked to sign an assent form to document his or her agreement. The assent document contains information very similar to this informed consent document.

If you agree to allow your child to participate in, his or her involvement will last 50 minutes in each lesson for one unit of content up to 6 or 7 lessons. During those observations, both [TEACHER'S NAME] as well as your child will be audio- and video-taped. If you do not allow your child to participate in this investigation, the student researcher and teacher will discuss to move your child to another table without audio-and video-recorders

During each lesson, the student researcher will also make notes about the interactions observed in the classroom. These notes will use fake names rather than real names to help protect your child's identity.
There are no foreseeable risks to your child as a participant in this project.

The researchers hope that this investigation will make a valuable contribution to science education by finding and developing teaching strategies that will help future and present science teachers to be more effective in their science teaching in the classroom.

All information (including audio and video tapings with written notes) will be kept in a locked location at all times. The only people who can access to the data will be the Principal Investigator and student researcher. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants. By initialing in the space provided, you verify that you have been told that audio and video recordings will be generated during the course of this study.

_______________ Parent/Guardian initials

Taking part in this research study is voluntary. Your child may choose not to take part in at all. Participating or not in this project will have no affect on your child's grade or relationship with [TEACHER'S NAME]. Even if you agree to allow your child to participate in this study, your child may stop participating at any time. If you disagree to allow your child to take part in this project, or if your child wants to stop participating at any time, your child's decision will not result in any penalty or loss of benefits to which he or she may otherwise be entitled. Any data collected regarding your child will be destroyed.

Questions are encouraged. If you have any questions about this research project, please contact the student researcher at parky@onid.orst.edu (Tel: 541-737-1824) or the Principal Investigator, Dr. Larry Flick, at larry.flick@oregonstate.edu (Tel: 541-737-3664). If you have questions about your child's rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-3437 or by e-mail at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered. You will receive a copy of this form.

Name of Parent/Guardian (printed):

____

___________________________________ ___________________________

(Parent/Guardian Signature) (Date)

Please initial the appropriate space:

_____ I agree to allow my child _______________________ to participate in this project.
Initial (Child's name)

_____ I DO NOT AGREE to allow my child ____________ to participate in this project.
Initial (Child's name)

APPENDIX F

ASSENT DOCUMENT [student form]

Project Title: Analyzing Teachers' Explicit Teaching Strategies and Student Discourse For Scientific Argumentation
Principal Investigator: Larry Flick/Department of Science and Mathematics Education
Student Researcher: Young-Shin Park

We are doing a research study. A research study is a special way to find out something. We are trying to find out your teacher's teaching methods, which help you think scientifically while you discuss certain science content with your teacher and your friends. Thinking scientifically means how well you can use your data collected from your lab experimentation to support your hypothesis. This form is about the study, so you can learn about the study and decide if you want to be involved in or not. You can ask any questions. After all of your questions have been answered, you can decide if you want to be in this study or not.

If you decide to work with us, we will ask you to allow us to record you and your classmates in groups during science lessons with audio and video equipments. We will visit your classroom several times for this purpose. We will set up one video camera in the classroom and a few audio recorders on the selected groups of tables to record what you are doing and what you are talking. You just behave as usual while we observe your lessons. If you don't want to be audio or video taped, that is okay and you can be moved by your teacher to an area where you won't be recorded.

When we are done with this study, we will write a report paper about what we found out. We will not use your name in the report.

You don't have to be in this study if you don't like. It's up to you. If you say okay now, but you want to stop later, you can do that. All you have to do is telling us about your decision.

If you agree to help us observe you, please sign your name.

I, ______________________________, want to be in this research study.
(Print your name here)

______________________________ (Sign your name here)

______________ (Date)

APPENDIX G

2002-2004 Official Scientific Inquiry Scoring Guide

Benchmark 3

	Forming a Question or Hypothesis Based on observations and scientific concepts, ask questions or form hypotheses that can be explored through scientific investigations.	**Designing an Investigation** Design a scientific investigation to answer a question or test a hypothesis.	
6	A) Provides a focused rationale for the investigation by using the most relevant background scientific knowledge or preliminary observations. N) Forms a question or hypothesis which can be answered or tested using data and that points toward an investigation of scientific relationships (e.g., dependency, correlation, causation). C) Expresses question or hypothesis along with the application of background information dearly enough to imply an appropriate investigative design.	A) Proposes precise, safe and ethical procedure that demonstrates application of relevant scientific principles and procedures. B) Presents a practical design that should provide data of sufficient quantity and quality to answer the question or test the hypothesis and investigate possible relationships (i.e., cause/effect). C) Communicates a unified design and logical, detailed procedures that can be replicated.	6
5	A) Provides background scientific knowledge or preliminary observations and shows how they are connected to the investigation. N) Forms a question or hypothesis that can be answered or tested using data and provides focus for a scientific investigation. C) Expresses question or hypothesis along with the explanation of background information clearly enough to imply an appropriate investigative approach.	A) Proposes logical, sage, and ethical procedures in a design with no scientific errors. N) Presents a practical design that should provide data of sufficient quantity and quality to answer the question or test the hypothesis (i.e. fair test). C) Communicates an organized design and detailed procedures.	5
4	A) Provides background information or observations relevant to the investigation. N) Forms a question or hypothesis that can be answered or tested using data gathered in a scientific investigation. C) Expresses a question or hypothesis along with background information.	A) Proposes logical, sage, and ethical procedures in a design with only minor scientific errors. N) Presents a practical design that should provide data applicable for answering the question or testing the hypothesis, although the quantity of data may be insufficient. C) Communicates a plan including important specific procedures.	4
3	A) Provides background science knowledge or preliminary observations that are either irrelevant or incomplete. N) Forms a question or hypothesis that can be investigated using data but not directly answered or tested. C) Either question, hypothesis or the explanation of background information is undear or incomplete.	A) Proposes safe, ethical procedures in a design that contains some significant scientific errors. N) Presents a design that should provide data somewhat applicable to the question or hypothesis. C) Communicates a general plan with few procedures, and generally lacks detail.	3
2	A) Provides background science knowledge or preliminary observations that are inappropriate or substantially incorrect. N) Forms a question or hypothesis that can not be investigated using data. C) The question or hypothesis is included with no supporting explanation.	A) Uses little scientific knowledge or does not consistently use reasonable, safe, or ethical procedures in a proposed design. N) Presents a design that is impractical or likely to produce flawed data. C) Communicates an incomplete plan.	2
1	A) Background information not included. N) Forms a question or hypothesis that can not be answered or tested. C) No hypothesis or question included.	A) Uses minimal or incorrect scientific knowledge and unacceptable procedures in a proposed design. N) Presents a design that will not provide applicable data. C) Communicates a plan that is unclear or illogical.	1

2002-2004 SCIENTIFIC INQUIRY SCORING GUIDE – Benchmark 3
[A= Application of Scientific Knowledge, N= Nature of Scientific Inquiry, C= Communication]

2002-2004 Official Scientific Inquiry Scoring Guide

Benchmark 3

	Collecting and Presenting Data Collect, organize, and display sufficient data to support analysis.	**Analyzing and Interpreting Results** Summarize and analyze data including possible sources of error. Explain results and offer reasonable and accurate interpretations and implications.	
6	A) Records accurate data completely consistent with complex procedures. N) Transforms data into graphic displays/formats that highlight information and patterns to support interpretation of relationships. C) Creates displays (e.g. data tables) for communicating observations or measurements, using appropriate units, precisely and thoroughly in a logical and organized fashion.	A) Uses scientific concepts, models, and terminology to report results, discuss relationships, and propose explanations. B) Provides evidence that design, procedures, and results have been reviewed to identify some obvious limitations and sources of error. C) Explicitly uses the results of the investigation to support conclusions that address the question or hypothesis.	6
5	A) Records accurate data completely consistent with the planned procedure. N) Transforms data into displays/formats that present and clarify results and facilitate scientific analysis and interpretation. C) Creates displays (e.g. data tables) for communicating observations or measurements, using appropriate units, in a logical and organized fashion.	A) Uses scientific terminology to report results, identify patterns and propose explanations. N) Provides evidence that the design or procedures have been reviewed to identify some obvious limitations or sources of error. C) Explicitly uses the results of the investigation to support conclusions that address the question or hypothesis.	5
4	A) Records reasonable data consistent with the planned procedure. N) chooses data transformations that are valid and complete (but do not necessarily facilitate scientific analysis and interpretation). C) Creates displays (e.g. data tables) for communicating observations or measurements, using appropriate units, in an organized fashion.	A) Uses scientific terminology with minimal errors to report results and identify patterns, and attempts to propose explanations. N) Provides evidence that the design or procedures have been reviewed to identify some obvious limitations or sources of error. C) Uses the results of the investigation to generate conclusions that address the question or hypothesis.	4
3	A) Records reasonable data consistent with the planned procedure with some obvious errors. N) Choose data transformations that are sometimes invalid or incomplete. C) Creates displays for communicating observations or measurements that are somewhat incomplete or disorganized.	A) Uses scientific terminology with major errors to report results and identify obvious patterns, or fails to propose explanations. N) Provides evidence that the design or procedures have been reviewed, but reported errors are trivial or illogical. C) Develops conclusions related to the question or hypothesis, but support from the investigation is lacking.	3
2	A) Records data inconsistent with the planned procedure. N) Chooses data transformations that are substantially incomplete. C) Creates displays for communicating observations or measurements that are substantially inaccurate, incomplete, or disorganized.	A) Uses scientific terminology incorrectly to propose explanations to report results or identify patterns or proposed explanations. N) Provides minimal evidence that the design or procedures have been reviewed and reports the investigation ignoring errors. C) Presents conclusions that are not clearly related to the question or hypothesis.	2
1	A) Records data unrelated to the planned procedure. N) Presents results in ways that are confusing or incorrect. C) Does not display data.	A) Does not relate explanation to investigation or explanation has been omitted. N) Does not review or report the investigation. C) Develops conclusions unrelated to the question or hypothesis.	1

2002-2004 SCIENTIFIC INQUIRY SCORING GUIDE – Benchmark 3
[A= Application of Scientific Knowledge, N= Nature of Scientific Inquiry, C= Communication]

APPENDIX H

Name____________________________________ Period ______________

Rocket Balloon Lab

II. Materials: 2 straws, meter stick, sausage, balloon, making tape, stop watch, scissors.

III. Procedures

1. Tape the two straws together, butting them, using a small amount of tape.
2. Measure the straws to 35 cm. put the remaining amount inside the balloon.
3. Tape around the straw and the balloon making a tight seal.
4. Blow up the balloon so that it is 30 cm. in length. Be sure the balloon is 30 cm. for all trails.
5. Hole the balloon as in illustration, ill. One
6. Release the balloon while you start the stop watch.
7. When the balloon touches the desk or passes below the desk top-stop the watch.
8. Repeat one more time.
9. Cut off 5cm. of straw
10. Repeat #1 through 9. Record data and observations

IV. Data

Length of Nozzle

	35	30	25	20	15	10
Trial 1						
Trial 2						
Average						

Observations

35cm

____

30cm

____

25cm

____

20cm

____

15cm

____

10cm

____

V. Analysis and Conclusions

APPENDIX I

Argumentation by Toulmin Analysis

October 26, 2004 (4th period: whole class discussion)		
Teacher	**Student**	**Toulmin**
Designing the investigation is how you talk about it step by step, how you would do the investigation. Number 1, do this, number 2, do this. I want to know what you have written for step 1. What is the first thing that you said you should do on your experiment? Holly?		
	Select the different balls that you are going to use	Claim
You would think that the first thing you would want to do is select three different kinds of golf balls. This has to be the first thing on your write-up, Ricky. It should be there somewhere. What is the next thing you have. We have selected three different golf balls. What is the next thing you are going to do?		Claim
	Select a club	Claim
OK, what club are you going to use. JD, are you doing this with us?		
	Yes.	
John, are you with us yet? Do you have step 1 and step 2 written down yet. The first thing is to select the three balls. Who has a third thing? Halley?		
	I would [say force].	Claim
You guys are really hot. You are much better than what I've got on my first couple of periods. You have come up with controlling how much energy you hit it with. Be sure you hit the ball with the same amount of force, right? What is another thing we should have?		Claim Data
	[where to hit]	Claim
OK, where are you going to hit it from? What is your reference point? What do you have for the next thing? Is that it? How about you? Tell me the next thing you would do. So far we have selected the three balls, we have selected the club, we have talked about where we		

are going to hit it. Anything else? Oh, the same kind of force		
	Hit the ball on the tee	Claim
put the ball on the tee and?		
	Hit it.	
OK, now what?		
	[measure the distance]	
Measure it. OK, we are going to measure how far it goes. That is kind of talking about trials, is it not? Have you identified how many trials you are going to do? How many are you going to do?		
	I just said do [lots].	
Just do lots. Lots is kind of open ended. Keep hitting it until you get tired of hitting it?		
	No, like [unlimited], but a lot.	
Maybe it would be better to get more of a specific number rather than lots. What is your definition of lots? That would be how many trials?		
	Two or three.	
Two or three is lots to him		
	A lot of trials on three brands.	
You only have to hit it nine times.		
	Yeah, that is a lot.	
Think about this class, we did the rocket balloon lab, and we had 16 trials with each nozzle length times six nozzle lengths, and we still didn't		
	We had [inaudible]	
You had to do two times six		
	I would do 20 times per ball.	
20 trials per ball. Has anyone discussed whether you are going to hit all 20 with one ball and then put the		

second ball up there, and then hit 20 of those, or are you going to make it random, or are you going to hit Ball 1, Ball 2, Ball 3, Ball 2, Ball 2, Ball 3? What would be the best way to design your investigation? Victor, what do you think?		
	If you get three separate people to hit at the same time. . .	Data
	No, they might not all hit with the same force	Rebuttal
	I think the best way would be to hit one ball at a time, Ball 1, Ball 2, Ball 3, because of the fact that you won't be tired, because it is only three trials, so you will be able to hit it with mostly the same amount of force. Then it will be closer to [inaudible] than it should be	Qualifier
	How about if you do it with one ball at the	Rebuttal

	same [inaudible]?	
	The tee is still there	
	What if they hit at an angle?	Rebuttal
That is another thing. Remember, the more trials you do, the more you balance out those factors. If you have one bad hit, the other one is going to [inaudible], and kind of eliminate that. One thing that we didn't talk about under the rocket balloon lab that I saw happening was somebody said, "Oops, we are going to do that one again, it didn't work right." You can never throw out a piece of data because you didn't get what you want. You have to take all the data down, whether it worked or not. We have discussed a couple of things – hitting the balls, A, B, C, A, B, C. That would take care of a problem of say I am going to hit the Top Flight on Monday when it is sunny and there is a nice tail wind. I am going to hit the Ben Hogan on Tuesday, when it is clear but there is no wind. I am going to hit the Titlist on Wednesday, when it is raining and there is a wind blowing in my face. Could you do that? Would that mess up your results?		Data Data
	[All saying yeah]	
So you want to be sure that you try to control the factors. If you were hitting a 1, 2, 3, 1, 2, 3, 1, 2, 3, they would all be under the same kind of conditions, wouldn't they? Ricky?		
	[I] hit the balls on the same day, but on a different	
That is one of the things that you have to work to control. You either have to have somebody who is really good at golf, with a [..] swing, that means you hit it virtually the same each time. It could be a great hit one time and the next time who knows where it would go. You wouldn't want to use me as your person that is doing it.		Backing Data Warrant
	You could have a	Data

	machine do it	
You could have a machine. I want you now to look over your answer to Daily Science 1. You can pass it to another person in your team and they could look over your answer to Daily Science 1. It is okay to make extra notes on the back of your paper if you want, but in just exactly one minutes and five seconds, we are going to move on to Daily Science 2. Look it over, talk about it, and see what you can come up with. Help each other out. OK, time is up. Let's talk about the next one. You were told to write down the things [inaudible]. Tell me one thing you are trying to control in this experiment		
	The soil.	Claim
The soil, good. Alex, another thing they were controlling in this experiment?		Claim
	The light?	Claim
No. Penny, another thing they were controlling in this experiment?		
	Fertilizer.	Claim
Stacy, another thing they were controlling		
	The light.	Claim
I said the light wasn't one of them. Nichole, another thing we were controlling?		
	The plants?	Claim
The plants, I'll take that. Riley, another thing?		
	The kinds of soil	Claim
Same size. Another one?		
	The amount of water.	Claim
The amount of water. Different plants, we control the kinds of plants. We are going to have plant 1 and plant 2. Identical pots. Same soil, same watering, and same fertilizer. You were supposed to write down the things that were controlled. What was the problem with this experiment?		
	There were two different kinds of sunlight and two different	Data

	kinds of plants	
We did not control – remember in science, we try to only have one variable that we are testing. They had two different things. They had two different plants and they had two different kinds of light. When you were done, you didn't know if the plant grew better because it was a better plant, or if it grew better because it had a different light. That is why the lab was not well designed. Day three, they ask you to identify types of energy in this classroom. Who has one?		Warrant
	Overhead	Claim
The overhead is not a kind of energy		Claim
	The lights?	Claim
Light is a form of energy. Another one?		Warrant
	The plug ins?	Claim
The plug ins in a source of what kind of energy?		
	Electric	Warrant
Electrical energy, right. So far we have light or sunlight and electricity. Are there any other kinds of energy in here? Holly?		
	The phone jack?	Claim
What kind of energy is that?		
	Electrical.	Warrant
We have that already. What about it? What comes from it?		
	Waves.	Backing
Sound energy, waves of sound. That is a type of energy, isn't it? Another one?		
	Gravity.	Claim
Gravity is not considered a kind of energy, sorry.		
	Computers.	Claim
	They have electrical.	Warrant
Computers run on electricity. Anything else?		Warrant
	[air].	
Something about the air, right?		
	Body.	Claim
Your body. The energy of your motion. You are burning sugars in your body right now. Energy in the		Data Warrant

form of motion. You are also releasing another kind of energy		
	Gas.	Claim
	Somebody could be radioactive, so have energy.	Data Claim
There is one more thing. It sure is cold in here. No, it's not, it must be some?		Data
	Heaters.	Claim
Heat energy. Here are the ones we've got – sunlight, electricity, your motion, sound and heat. Take a moment to write some of those down. We have one more Daily Science to do, and that was [inaudible] yesterday. It was another designing of the investigation, so we are going to talk about that in a moment. Remember what we did yesterday? We were trying to find out who was the fastest boy and girl in the classroom. I am going to go through the same thing I did before. I am going to ask you to tell me what is the first thing you need to write down to design this investigation? Jessica, what did you write down?		Warrant
	I don't know	
We are designing this investigation. What is the first thing the person is going to do if they follow your directions?		
	Just guess	
Just guess? What are they going to guess at?		
	I just guessed on your paper	
What did you guess? You didn't guess anything. Then the answer is I don't know. Let's go ahead and ask Sierra, then?		
	I said I would get the boys and the girls and separate them so they can do it separate	Claim

The first thing she said, and it doesn't necessarily have to be in this order, ladies and gentlemen, but you have to have these things in your answer. How are you going to group the students? She is going to have all the girls in one group and all the boys in another group and they are going to do what? What is the next thing you think you should have?		
	Get all the proper equipment for the thing, like stopwatches and lines. . .	Claim
One of the things that we talked about yesterday for those of you who were paying attention was fastest at what, determine what they are going to be fastest at?		
	You need a stopwatch either way, for the fastest, because you are racing against the time	Data
Race against time, okay.		
	If it was fastest at drawing something, fastest at running somewhere, fastest at anything, you need the stopwatch to see how much time it took them to do that.	Data
People sitting next to each other, and I said, "Ready go," and I can tell who finished first and then say		

[inaudible		
	Then you need to find out how long for the other people in the class.	Data
You have to know where you are going to start, aren't you? It is a pretty good idea to know where you are going to end, too. Everybody line up at the line, I am going to shoot off the gun, and start the stopwatch. You have better know when the race is over. If you told me how far it is going to be, are they just going to run until they get too tired and they fall.	The reference point of something.	Claim Data
	If they collapse in exhaustion, and then they die.	Data Claim
I think we better not do that. Does anyone have anything else that you think your design needs? Listen to me, and I am going to tell you this again, you are supposed to be developing your skills of designing now, because next week you are going to be assessed, and it is going to go into your portfolio to be able to do this. You have to start thinking linear, part one, two, three, four, five. What is the first thing and then the second thing and then the third thing that I am going to do? We do not have everything down on this that we should have. I don't see a lot of real aggressive thinking going on in trying to come up with these things. It is so much easier just to sit back and let Mr. Field or somebody else give you the answer and you write it down. That isn't going to happen next week, ladies and gentlemen. You are going to be doing your own stuff.		
	[noise]	
He is talking about football. He is going to have the girls tackle the girls. That should be fun to watch. They would be good at it, I know. One of the things he talked about was the equipment. If you are running we talked about is everybody going to be wearing their shorts? Are they going to be wearing jeans? Are they going to be wearing their swimsuits? What are they going to be wearing to do your experiment?		Claim Data Data

	It is not about that, but you should mark your data and average everything out after everything.	
You are talking about data collection, which to me is trials. How many times are you going to have people do this to be sure your results are accurate? How many people said, ah, if they run one, that is enough?		Claim Data
	Twice.	Data
Two times? Did you write that down in your non-guess that you never wrote down?		
	Something like that, or aren't they going to be more tired the next time they are running?	Data
After a rest, maybe.		
	You give them a 15 minute rest.	Data
	No.	
You have to do things different		
	Take a shower.	Data
Once again, I expect it to be better this time. I want you to share your answer on Daily Science, or with other members of your team, so you can see if you have done what we have talked about. Number of trials? Starting point? Ending point? Controlling the variables that would make you have accurate experiments. Do that right now, please. Take a look. Make sure you have your name on it, you have 3 and 4 on it, you have Daily Science 6 on it. Get that on there correctly, please. Notes from yesterday, out in front of you now. If you were absent, come get a worksheet from yesterday. Let's go to page 52 in your textbook.		Claim

APPENDIX J

Argumentation by Toulmin Analysis

*Mr. Field (October 12, 2004, *4th period)		
TEACHER	**STUDENT**	**Toulmin**
I am going to use as small amount of tape as possible and still make that tight, so air can't escape. Why would I want to use the smallest amount of tape possible? Yes?		Qualifier
ex	So it doesn't weight it down	
So it doesn't weight it down. What do you mean by weigh it down?		Qualifier
	So that it doesn't go [up]. If it has too much. .	
You are talking about some force here. What force are you talking about?		
	Gravity.	Data
You are talking about gravity and you seem to think that is something weighs more, gravity pulls on it more. Is that right?		
	Yes	
OK, is that what you all think? If I went to the top of the school and I dropped a golf ball and I dropped a ping pong ball, the golf ball would hit the ground before the ping pong ball. Is that right?		Data
	No	
	[All talking at once]	
OK, some of you believe that gravity pulls on everything with exactly the same amount of force		Backing
	It depends on what the mass is	Qualifier
You are saying that the mass makes a difference		Rebuttal
	If it is [different in mass].	
Sebastian?		
	It depends on how much [it weighs]	
.	In space you can drop a hammer and a feather and they will land on the ground at the same time	Qualifier
We have a difference of opinion here. Let's see if I can find two things that are different masses here. Let's make sure they are quite a bit different. I've got this book, and that is quite a bit of mass there, isn't it? A lot more mass there than say the top of my pen. Wood everyone agree that these are quite different in mass?		Data
	[Unanimous yes]	
If I drop these, one should hit the ground before the other,		

right? [Noise] What did you see?		
	The same time	Qualifier
	The book	Rebuttal
	The same time	Qualifier
They hit the ground at the same time. That's because gravity is a constant. It pulls on all things with exactly the same amount of force. Even though you think that is not true, that is. Gravity doesn't care if you are big or small. It pulls on you with the same amount of energy		Data Qualifier Backing
	If a short person falls off a building and a heavy person falls off a building, they will both hit the ground at the same time?	Data
In fact they have even proved it, because there have been skeptics. Can you believe there would be skeptics in the world that say, "That's not true." They said, "What about a feather?" That is what most people say. If you drop a bowling ball and a feather at the same time, they are not going to hit the ground at the same time. Well, they said, that is because of air resistance. It is underneath the feather and makes it flutter down. Let's see what happens if we take all the air away. Have a bit huge column and they pump all the air out. They have a little thing that they pull so both things fall at the same time. The feather and the ball hit the ground at the same time. Gravity is a constant.		Rebuttal Claim
	Actually when you step on the ground, the ground is up against you, and otherwise it would be kind of hard for us to walk.	Qualifier
Exactly right. Yes		
	[from different height?]	
If they drop it from different heights? Then they would not hit at the same time, because they both accelerate at the same speed. Let's try to get back on what we were talking about here. What we were talking about is trying to use as small amount of tape here as possible, because we don't want to have extra mass, because we know that even though they hit the ground at the same time, it took a lot more energy for me to pick this up than it did for me to pick up the top of my pen. If you are trying to overcome the force of gravity, mass plays a big part. A lot of the metals that you take for granted now, whether it be aluminum or really light plastics, or even other very light strong metals, they were originally made because they wanted to take over and not have as much mass. We have those things in our lives now, but they were originally made spacecraft or airplanes to try to reduce the amount of weight. Next step – just a second and I'll answer your question – we want this nozzle to be 35 centimeters		Qualifier Rebuttal Qualifier

long. I have discovered over time that the best balloons to use for these are called sausage balloons.		
	So can we eat them?	
I had quite a struggle getting enough sausage balloons. I used to be able to buy them, but now they are hard to find. Anyway, what you are going to do when you get your own – and each group is going to have their own sausage balloon – you have to stretch them out first so they are easier to blow up. When you are talking to your groups, you are going to want to be sure that you pick someone in your group who can actually blow up a balloon. There are some people whose lungs aren't strong enough to blow up a sausage balloon. I am going to measure this, and I am going to find out where 35 centimeters is – it is right there. I am going to put the extra nozzle into the balloon like that. Then I am going to take a small amount of tape, and I am going to carefully put half of it on the balloon and half of it on the straw, and try to make this an airtight seal. OK, what is your question?		
	Are we going to do this today?	
No, we are going to start it tomorrow. We are going to be working on it, but you will begin the actual experiment tomorrow. Now remember we talked yesterday about controlling variables, so we had two things on your graph. We were talking yesterday the two things were time and distance. In this one, basically, we have length of nozzle and time of flight are our two variables. What of those two things do you know before you are going to start. One of the things we have to control is making sure that the balloon is the same length each time. It wouldn't do to have it really small one time and real big another time, because that would make our results not true. Would you help me a minute here, Holly. I am going to blow the balloon up. I am going to lay the nozzle right here on the ruler. I am going to blow up to 30 centimeters. You are going to tell me when it is at 30 centimeters. OK. There is my rocket balloon. Where did it go? If this was an actual experiment, one of you is going to say, "Ready, go." Another person is going to start the stopwatch. It hovered for awhile. As soon as it past the plane of your table, you stop the stopwatch, and that is your flight. OK. You are going to do that twice for each nozzle length. Then you are going to cut it off to 30, 25, 20, 15 and 10. Your goal now is to begin thinking about which nozzle length is going to have the balloon fly for the longest amount of time. Let's have a little class discussion first. What things do you think might influence whether it flew for a long time or a very short time. What do you think?		Claim Data Qualifier Rebuttal Warrant Claim
	The amount of air. .	Claim
The amount of air we will control. Each time we are going to have 30 centimeters of air in the balloon.		Data
	It would probably hover for longer if the straw was longer,	Claim Data Warrant

	because it takes the air more time to get out	
OK, there is one person's point of view. He is saying that air – remember I am going to talk about two different types of energy here – you have potential energy and what is the other one?		
	Hyper.	
No, kinetic energy. Potential energy, I had to put a lot of energy into blowing that up. The energy that I just used stored in that balloon. When I release it, it is kinetic energy. He is saying that after you have stored the energy in the balloon, it is going to come out in a more measured fashion, because it has to go through a longer nozzle. That is going to cause it to fly longer. Can anyone think of a reason why he might be wrong? Yes?		Backing
	Because the longer it is, the longer [it stay].	Data Claim
We also have to deal with the factor that there is more mass here, and more mass means that it is going to be harder for this to go up against the force of gravity. We have some balancing acts we have to do here		Rebuttal
	The shorter nozzle might be [less] weight	
He is saying maybe we should go with the shorter nozzle because there won't be as much mass. Can anyone think of a reason why this short nozzle might not be the best answer?		Data
	Then it would have to come out [inaudible] and the air might leave faster	Warrant
The air might leave faster. That is a possibility. You guys are doing a great job thinking about reasons why you are going to choose the nozzle length that you are going to choose. Now we are going to start really talking about it. Yesterday we read Newton's law, didn't we, on page 44, right. Everyone should be looking at Newton's first law of motion. You need to get out a piece of paper		Warrant
	A new one or a note?	
A brand new one. Put your name and period 4, and Rocket Balloon Lab as the assignment		
	Everybody?	
Everybody does their own work on this. You work as a team, but you are doing your own work. Once again, name on the top right hand, period four, and Rocket Balloon Lab		Data
	What about the [time], daily?	
Yes, but not this minute. After you have headed your paper correctly, I need you to, in nice big letters on the top of the paper, write this – instead of writing hypothesis – you are going to write Framing the Investigation. This is where you are going to tell me which nozzle length you think is going to work best and also why you think it is going to work best.		Claim Warrant

	It doesn't matter if it is wrong, does it?	
It does not matter if you are incorrect, if you choose to write one. The only way it can be wrong is if you don't make a guess and you don't tell me a reason why you chose the distance you did.		Rebuttal
	Are these the same, how long it stays up or how high?	
We are going to do something called the claims evidence approach to science. This is the newest way you are supposed to do these activities. These aren't called lab anymore, but inquiry skills. Inquiry means thinking creatively. It used to be that you started at point A, hypothesis, and you want to point B, or F, actually, conclusion. That is not the way you are supposed to do science anymore. You need to see science as a circle. You start with an idea. You do an investigation. As you are doing an investigation, new ideas occur to you, new things you'd like to learn. When you get to the end, you actually have five more things you might like to do. The claim that I am going to lay on you comes from your textbook. I'd like you to start now by looking at Newton's first law on page 48 and try to restate that. That is the claim. The book makes claims all the time and kids get in the habit of just willy-nilly walking along, "Well, the book says it is true. It must be true." Oh, yeah. What if it is not true. Let's see if we can prove if it is true or not. That is what the claim is. The claim I am giving you is Newton says this. See if you can take his words and put them in your own words		Backing Warrant Data Warrant Claim Data Warrant
	When something moves it must stop	Claim
If something moves, it must stop. Is that what Newton's law says?		
	No	
	It says it won't stop unless there is [another] forces	Claim
Right, it says it won't stop unless there is another force acting on it, right? Will it move when it starts? If I put my rocket balloon here, wherever I put it, if I set it here, is it going to move?		Claim Data
	No.	
It never will move, will it, unless an equal and opposite force is placed on it. The first part of Newton's law says anything at rest can stay at rest. In other words, if you put something in one place, it won't move unless there is some energy added to it. Newton's first law continues, if this is shooting along, it will continue to shoot on forever unless. .		Data Warrant Data
	Another force stops it	Qualifier
Another force stops it or slows it down		Qualifier
	Cool.	
	The claim says that an object will not	Claim

	move unless a force moves it, and also that an object will keep moving unless another force stops it.	
Good. You need to address both sides of Newton's first law – what happens when it is not moving and what happens when it is moving. OK, that's the claim. I am saying this is what Newton says, and now we are going to do the rocket balloon lab to try to find out if the book is lying to us or not, or if we can actually prove what he says is true. That is called the evidence. What evidence can we gather through this investigation to either prove or disprove this claim? When you are talking about, let's go back through Chapter 1 and Chapter 2 and begin to develop a list of vocabulary words that you might want to have in your framing that would help explain your position on whether this claim is true of not. Go back into your books and raise your hand if you can think of a word that we might want to use to describe this.		
	Velocity.	Data
Velocity. Now remember what velocity is? That is average speed, but you tell what direction, right. Another one?		
	[reference point]	Data
Oh, very good. The last class didn't get reference point. You don't have to write these yet. Let's just generate them first. More words? Anything that you think is going to help you describe what you think is going to happen with this rocket balloon.		
	Acceleration	Data
Acceleration. Another one?		
	Time.	Data
Yes, you have to have time. Yes?		
	Distance.	Data
Distance. Yes.		
	Force.	Data
Force, oh, yeah, we better have that word in there somewhere.		
	Motion	Data
Motion. Any other words that you think might play a part.		
	Energy.	Data
Energy, okay. We said there were two kinds of energy. We haven't focused on them very much, but I'll write them down here – potential and . . .		
	Evidence	
Kinetic. Potential and kinetic energy.		
	Mass.	Data
Mass, that is a good one. Yes?		
	Inertia	Data
What is inertia? Does anybody know what inertia is?		
	[All talking at once]	
Good. When this thing is laying right here, inertia says it wants to stay there. It is going to take, in fact, if you have		Claim Backing

every tried to push a heavy object, like a car, for example, it takes a lot of energy, but once you get it going, you can get it going. Its inertia wants it to just sit there and do nothing. It is kind of like your big brother who is a couch potato and you can't get him off the couch. Once you get him up and moving, boy, does he get a lot of stuff done. Same thing. The other side of it is, once something is in motion, it wants to continue in motion, unless it is operated on by another force. You think this is a pretty big word for understanding Newton's first law. It is extremely important for you to understand that to understand Newton's first law, because anything at rest tends to stay at rest and that is inertia. Anything in motion tends to stay in motion, that is inertia. It is a good word. Another word?		
	Volume.	Data
Volume? You are going to talk about the volume of air in the balloon		
	Direction.	Data
Direction, okay.		
	Is another reason the balloon won't stay any longer is because it is not very aerodynamic.	
Everybody is dealing with the same one, so the only thing we are focusing on is the change in the nozzle length		
	Gravity.	Data
Gravity, thank you. I was hoping somebody would say that word. Am I dealing with a list of vocabulary words that you know their definitions from the work we have done in the last couple of days? If you don't know it, you can easily find it in Chapter 1 and 2? OK. The length of the nozzles.		
	Are we supposed to be writing this down?	
No. The nozzle could be 35, 30, 25, 20, 15 or 10. The first thing you are going to do, remember, you have to tell me what is going to happen. That means which one of these are you choosing. Why do you think it is going to happen? This is extremely important and the why uses these words. The what and the why need to use those words. I want you to get busy now writing up your framing of the investigation. It is going to tell me what you think is going to happen, which one of these is going to fly the longest, and why you think it is going to happen, using as many of these words as you can.		Warrant Claim Data Warrant
	We are trying which nozzle raises the balloon the highest?	Rebuttal
No, it is not highest. It is longest hovering.		
	Is this due?	
You put all of this down and the reason why, that fast?		Data
	I did it. .	
How many of these words did you use?		
	Not many.	

That's a problem.		
	You are supposed to use almost all of them or as many as you can.	Data
Did you use the words reference point in your description? What is the reference point in this particular lab?		Data
	The reference point is the top of your table	Data
Very good. The reference point is the top of your table. You want to be talking about that. Go ahead. Dylan has been kind enough to help us clarify our framing of the investigation. First of all, he says that 20 or 25 centimeter straw will work best. Now, you can't hedge your bets on a hypothesis. I'm sorry. Although it would be nice to do that and it would give you a greater chance to get it right, but you can only chose one distance. If you have chosen more than one, choose the one you want and write it down. You never say, "I think it might be about," you can't do that in this. It will fly best at blank centimeters. That is what it is. If you are wrong, big deal. You learned something from it. There is no way you can say, gee, I hope maybe it could possible be somewhere around the middle of the straw. That doesn't work		Claim Data
	But we don't know where you are cutting them at	
Starting with 35 and then 30 and then 25. .		Data
	I couldn't see. She was in the way	
Does anyone have one that you would like me to read to the class and dissect? A lot of you raised your hands at once. Let's choose yours. Why are you so afraid? You don't think it is good?		
	I might be wrong	Rebuttal

APPENDIX K

Argumentation by Epistemic Operation

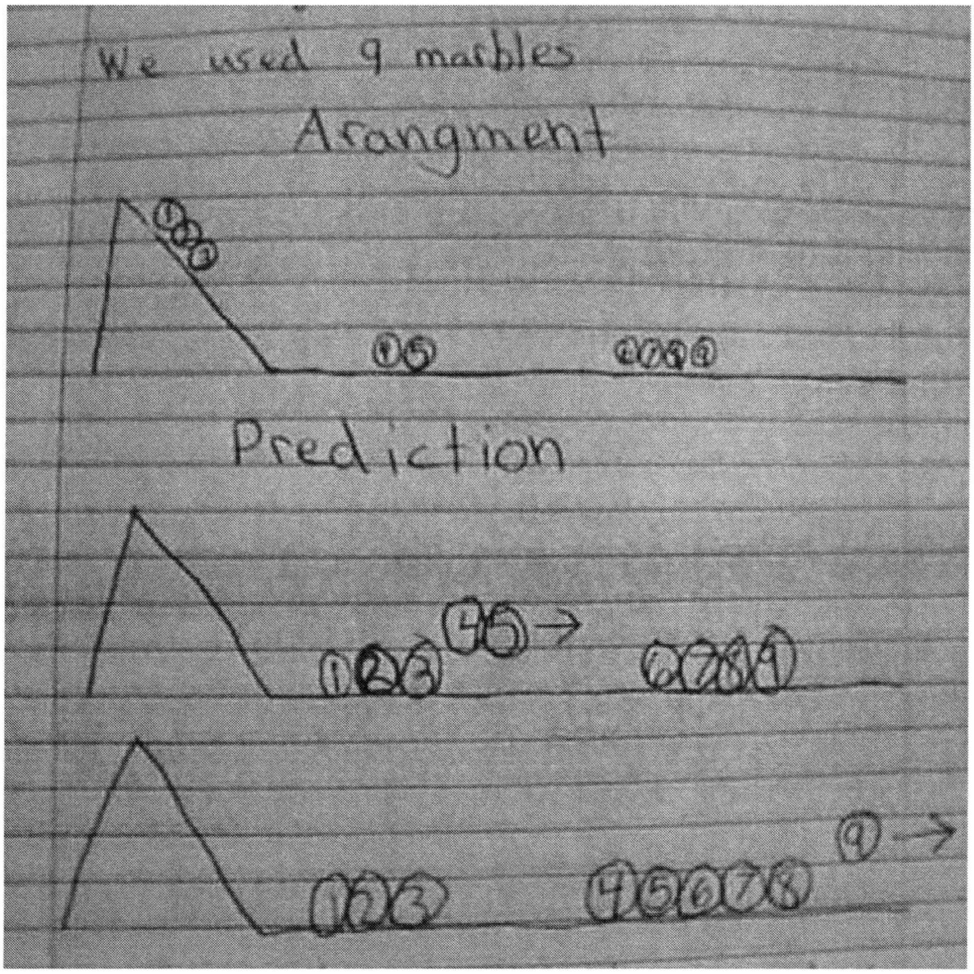
November 8, 2004: Marble activity		
Teacher	Student	Epistemic
I'm trying to think of all the possible patterns that I've come up with, and here is the next one that I can think of. We haven't done this one yet. Let's put one there and two there, and three there and see how it [comes] through.		Causality Appeal
	I think the energy that is transferred will get. . .	Causality
Make a hypothesis of what you think is going to happen.		Plausibility
	What do you think is going to happen? Don't forget the number, number one, two, three. What will happen? Make a prediction first. If I release the ball, what will happen to number one, number two, number three	Plausibility Appeal Plausibility Plausibility
	I think they would all end up together.	Deduction
	All three?	Appeal
	All three together.	Appeal
	How about if the speed is different? What about the speed? If I released a ball here? Would they go together?	Plausibility Plausibility Plausibility Plausibility
	Yes, they will go together,	Causality
Watch very carefully what happens. There is a lot of action and reaction as these go down. We have marbles that bounce backwards and then bounce forwards. Watch carefully to see what happens.		Causality Appeal Causality
	Why did you make a prediction first? It was so quiet.	
When you write down the results, it happens very, very, very quickly. You have to really be watching carefully to see what happens. I see some people moving the marbles by hand and reconstructing what happened in their experiment. That is an excellent way. You can check it with your partner. That is what you say happen? OK, how did they hit. You may have to take a couple of lines on your paper to describe everything that happened. First this happened, then this happened, then this happened, okay? I am very, very encouraged		Deduction

by the level of work that you are doing right now. Let's go ahead and see what we can come up with. One came down and hit two. What happened then?		
	Two went together	Appeal
I am going to do this in multi-steps. Here is step one. One came down and hit two. Here is my second step. Now what happened? Did one and two go together?		Appeal Appeal
	No.	
What did you see happen?		
	Number one hit two and then they all grouped together	Appeal
Then one and two, you are saying, moved together and hit three.		Appeal
	They caught up with three and they [transfer energy].	Causality
At this point what happened is all three of these, one, two, and three, went this way? Not everybody had that happen. Put the marbles back in the track while I am talking, please		Causality Plausibility
	One hit two, and then they [roll down], and two would make [hit another] three, and they weren't touching, but two would go back and forth and hit three	Causality
Here's what I saw happen. Let me go through this once and you see if you agree, okay. I saw one come down and hit two. Then I saw two go down and hit three, and then bounce backwards. Anyone see that?		Appeal Appeal
	Yes	
	That's now what I saw	
Two went back and hit one, went bink, bink, and then one and two continued going this way and catching up with three		Appeal
	Yes, that's what I saw, too	
Run it and see, because according to Newton's laws, for action and reaction, there should have been a reaction from three that would back into two. Check and see how marble two and three run into one another. Does marble two bounce back		Induction Causality
	No, it just slows down	Appeal
	It doesn't bounce back	Consistent
It slows down, okay. Colton says what happens if you put two and three closer to each other, toward the front part of the ramp, so they have more energy. OK		Deduction
	Yeah, it bounced back	Deduction
No, it didn't, it just slowed down. It didn't bounce back		Consistent
	Yeah, it did.	Deduction

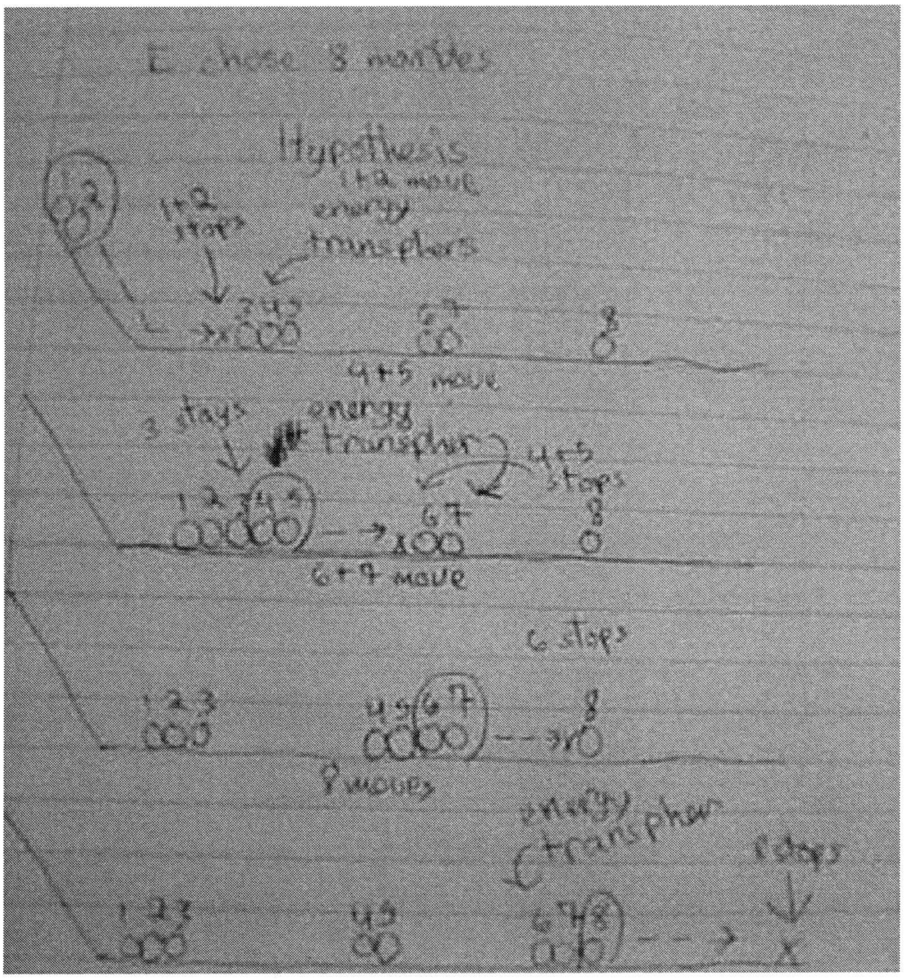
	It just slowed down. That is all it did. It doesn't go this way and then go that way	Consistent
I think we are ready to move on to four marbles. With four marbles I would like you to set them up on the following fashion. Marble one and marble two go into marble three and marble four. Make a predication of what you think will happen. When you have made your prediction, then you can some up and get your fourth marble. Maybe I'll bring it around to you. That might make it easier		Causality Appeal Plausibility Deduction Consistent
	OK, make a prediction	Plausibility
	I don't know	
	You don't know, but you are learning. Action, reaction and energy transfer. OK, what will happen?	Induction
	These two will come down and hit these two and it will. .	Causality
	Stop these two, and go with these two.	Causality
	Then these two will go [inaudible].	Causality
	So energy is transferred totally from one and two to three and four?	Causality
	Yes.	
	Are you sure? What about you?	
	I thought they would come down and hit these two and this one would go a little bit faster and this one would stop.	Causality
	What about this one?	
What I am going to do is I am going to open this up a little bit, and I am going to come up with five different combinations you can do with four marbles. I would like you to explore them on your own. What I am trying to inspire in your is to see all the different possible combinations that you can come up with, so when you do your own investigations, you can see how many choices there are for you to come up with.		Appeal Consistent Causality
	Do we do all of this?	
Yes, I want you to [write down].		
	All of them?	
You have ten minutes. Make some notes to yourself about how it works and what you think is going to happen, what actually happens. We are still building background information here		Causality Appeal

APPENDIX L

Marble Activity Lab Report



Claim: for every action, there is an equal and opposite reaction.
Prediction: The three marbles up top will accelerate at a speed that will make the first, second, and third marbles will hit the fourth and fifth marbles and the first, second, and third marbles will transfer its speed to the fourth and fifth marble which will roll over to the sixth, seventh, eighth, and ninth marbles. The fourth and fifth marble will have enough weight and spend to pouch the ninth marble to the end.
[One student from the 4th group in Marble activity: Nov, 8th 2004]



Claim: For every action there is an equal and opposite reaction.
Predication: I think when I release the first 2 marbles they will accelerate and transfer their energy throughout the track. Some of the energy will be exerted into friction.
[One student from the 3rd group in Marble activity: Nov, 8th 2004]

APPENDIX M

Argumentation by Reasoning Complexity

*Jim Harshfield
*October 12, 2004
*4th Block

TEACHER	STUDENT	REASON
I am going to use as small amount of tape as possible and still make that tight, so air can't escape. Why would I want to use the smallest amount of tape possible? Yes?		Elaboration
	So it doesn't weight it down	Explanation
So it doesn't weight it down. What do you mean by weigh it down?		Explanation
	So that it doesn't go [down]. If it hasn't too much. .	Justification
You are talking about some force here. What force are you talking about?		Elaboration
	Gravity.	Justification
You are talking about gravity and you seem to think that is something weighs more, gravity pulls on it more. Is that right?		
	Yes	
OK, is that what you all think? If I went to the top of the school and I dropped a golf ball and I dropped a ping pong ball, the golf ball would hit the ground before the ping pong ball. Is that right?		Explanation
	No	
	[All talking at once]	
OK, some of you believe that gravity pulls on everything with exactly the same amount of force		Justification
	It depends on what the mass is	Logical
You are saying that the mass makes a difference		Logical
	If it is [inaudible].	
Sebastian?		
	It depends on how much [inaudible]	Logical
.	In space you can drop a hammer and a feather and they will land on the ground at the same time	Logical
We have a difference of opinion here. Let's see if I can find two things that are different masses here. Let's make sure they are quite a bit different. I've got this book, and		Logical

that is quite a bit of mass there, isn't it? A lot more mass there than say the top of my pen. Wood everyone agree that these are quite different in mass?		
	[Unanimous yes]	
If I drop these, one should hit the ground before the other, right? [Noise] What did you see?		Elaboration
	The same time	Elaboration
	The book	Elaboration
	The same time	Elaboration
They hit the ground at the same time. That's because gravity is a constant. It pulls on all things with exactly the same amount of force. Even though you think that is not true, that is. Gravity doesn't care if you are big or small. It pulls on you with the same amount of energy		Explanation Generativity Logical
	If a short person falls off a building and a heavy person falls off a building, they will both hit the ground at the same time?	Elaboration Justification
In fact they have even proved it, because there have been skeptics. Can you believe there would be skeptics in the world that say, "That's not true." They said, "What about a feather?" That is what most people say. If you drop a bowling ball and a feather at the same time, they are not going to hit the ground at the same time. Well, they said, that is because of air resistance. It is underneath the feather and makes it flutter down. Let's see what happens if we take all the air away. Have a bit huge column and they pump all the air out. They have a little thing that they pull so both things fall at the same time. The feather and the ball hit the ground at the same time. Gravity is a constant.		Synthesis Justification Explanation Generativity
	Actually when you step on the ground, the ground is up against you, and otherwise it would be kind of hard for us to walk.	Logical
Exactly right. Yes		
If they drop it from different heights? Then they would not hit at the same time, because they both accelerate at the same speed. Let's try to get back on what we were talking about here. What we were talking about is trying to use as small amount of tape here as possible, because we don't want to have extra mass, because we know that even though they hit the ground at the same time, it took a lot more energy for me to pick this up than it did for me to pick up the top of my pen. If you are trying to overcome the force		Synthesis Explanation Synthesis Explanation Justification Explanation Logical Elaboration

of gravity, mass plays a big part. A lot of the metals that you take for granted now, whether it be aluminum or really light plastics, or even other very light strong metals, they were originally made because they wanted to take over and not have as much mass. We have those things in our lives now, but they were originally made spacecraft or airplanes to try to reduce the amount of weight. Next step – just a second and I'll answer your question – we want this nozzle to be 35 centimeters long. I have discovered over time that the best balloons to use for these are called sausage balloons.		
	So can we eat them?	
I had quite a struggle getting enough sausage balloons. I used to be able to buy them, but now they are hard to find. Anyway, what you are going to do when you get your own – and each group is going to have their own sausage balloon – you have to stretch them out first so they are easier to blow up. When you are talking to your groups, you are going to want to be sure that you pick someone in your group who can actually blow up a balloon. There are some people whose lungs aren't strong enough to blow up a sausage balloon. I am going to measure this, and I am going to find out where 35 centimeters is – it is right there. I am going to put the extra nozzle into the balloon like that. Then I am going to take a small amount of tape, and I am going to carefully put half of it on the balloon and half of it on the straw, and try to make this an airtight seal. OK, what is your question?		Logical
	Are we going to do this today?	
No, we are going to start it tomorrow. We are going to be working on it, but you will begin the actual experiment tomorrow. Now remember we talked yesterday about controlling variables, so we had two things on your graph. We were talking yesterday the two things were time and distance. In this one, basically, we have length of nozzle and time of flight are our two variables. What of those two things do you know before you are going to start. One of the things we have to control is making sure that the balloon is the same length each time. It wouldn't do to have it really small one time and real big another time, because that would make our results not true. Would you help me a minute here, Holly. I am going to blow the balloon up. I am going to lay the nozzle right here on the ruler. I am going to blow up to 30 centimeters. You are going to tell me when it is at 30 centimeters. OK. There is my rocket balloon. Where did it go? If this was an actual experiment, one of you is going to say, "Ready, go." Another person is going to start the stopwatch. It hovered for awhile. As soon as it past the plane of your table, you stop the stopwatch, and that is your flight. OK. You are going to do that twice for each nozzle length. Then you are going to cut it off to 30, 25, 20, 15 and 10. Your goal now		Elaboration Justification Explanation Justification Explanation

is to begin thinking about which nozzle length is going to have the balloon fly for the longest amount of time. Let's have a little class discussion first. What things do you think might influence whether it flew for a long time or a very short time. What do you think?		
	The amount of air. .	Elaboration
The amount of air we will control. Each time we are going to have 30 centimeters of air in the balloon.		Justification
	Do you want me to tell you why it would stay longer if [inaudible]	Explanation
Let's just brainstorm		
	It would probably hover for longer if the straw was longer, because it takes the air more time to get out	Explanation
OK, there is one person's point of view. He is saying that air – remember I am going to talk about two different types of energy here – you have potential energy and what is the other one?		Elaboration
	Hyper.	
No, kinetic energy. Potential energy, I had to put a lot of energy into blowing that up. The energy that I just used stored in that balloon. When I release it, it is kinetic energy. He is saying that after you have stored the energy in the balloon, it is going to come out in a more measured fashion, because it has to go through a longer nozzle. That is going to cause it to fly longer. Can anyone think of a reason why he might be wrong? Yes?		Justification Explanation
	Because the longer it is, the longer [inaudible].	Explanation
We also have to deal with the factor that there is more mass here, and more mass means that it is going to be harder for this to go up against the force of gravity. We have some balancing acts we have to do here		Justification Explanation
	The shorter nozzle might be [inaudible] weight	Justification
He is saying maybe we should go with the shorter nozzle because there won't be as much mass. Can anyone think of a reason why this short nozzle might not be the best answer?		Elaboration
	Then it would have to come out	Explanation

	[inaudible] and the air might leave faster	
The air might leave faster. That is a possibility. You guys are doing a great job thinking about reasons why you are going to choose the nozzle length that you are going to choose. Now we are going to start really talking about it. Yesterday we read Newton's law, didn't we, on page 44, right. Everyone should be looking at Newton's first law of motion. You need to get out a piece of paper		Generativity
	A new one or a note?	
A brand new one. Put your name and period 4, and Rocket Balloon Lab as the assignment		
	Everybody?	
Everybody does their own work on this. You work as a team, but you are doing your own work. Once again, name on the top right hand, period four, and Rocket Balloon Lab		
	What about the [inaudible], daily?	
Yes, but not this minute. After you have headed your paper correctly, I need you to, in nice big letters on the top of the paper, write this – instead of writing hypothesis – you are going to write Framing the Investigation. This is where you are going to tell me which nozzle length you think is going to work best and also why you think it is going to work best.		Generativity Explanation
	It doesn't matter if it is wrong, does it?	
It does not matter if you are incorrect, if you choose to write one. The only way it can be wrong is if you don't make a guess and you don't tell me a reason why you chose the distance you did.		Synthesis
	Are these the same, how long it stays up or how high?	Logical
Don't write anything other than what I am asking you to do right now. Do you have that done? I am going to introduce you to a new way of doing science, if you did not see it last year. Yes, sir?		Explanation
	How long is the [nozzle]	
Don't worry about that just yet. We will get to that in a minute. Yu have a tendency to want to jump ahead, which is great, but you have to [inaudible] right now. We are going to do something called the claims evidence approach to science. This is the newest way you are supposed to do these activities. These aren't called lab anymore, but inquiry skills. Inquiry means thinking creatively. It used to be that you started at point A, hypothesis, and you want to point B, or F, actually, conclusion. That is not the way you		Generativity Elaboration Explanation Explanation

are supposed to do science anymore. You are need to see science as a circle. You start with an idea. You do an investigation. As you are doing an investigation, new ideas occur to you, new things you'd like to learn. When you get to the end, you actually have five more things you might like to do. The claim that I am going to lay on you comes from your textbook. I'd like you to start now by looking at Newton's first law on page 48 and try to restate that. That is the claim. The book makes claims all the time and kids get in the habit of just willy-nilly walking along, "Well, the book says it is true. It must be true." Oh, yeah. What if it is not true. Let's see if we can prove if it is true or not. That is what the claim is. The claim I am giving you is Newton says this. See if you can take his words and put them in your own words		
	Do we just write it?	
You don't write it word for word. You put it in your own words that make sense to you. What is Newton's first law when you read it? How does it make sense to you? Read it over. If you still don't get it, raise your hand, and I'll try to help you. Let's hear what [inaudible] says Newton's first law is.		
	When something moves it must stop	Generativity
If something moves, it must stop. Is that what Newton's law says?		
	No	
	It says it won't stop unless there is [opposing] forces	Generativity
Right, it says it won't stop unless there is another force acting on it, right? Will it move when it starts? If I put my rocket balloon here, wherever I put it, if I set it here, is it going to move?		Synthesis
	No.	
It never will move, will it, unless an equal and opposite force is placed on it. The first part of Newton's law says anything at rest can stay at rest. In other words, if you put something in one place, it won't move unless there is some energy added to it. Newton's first law continues, if this is shooting along, it will continue to shoot on forever unless. .		Generativity Explanation
	Another force stops it	
Another force stops it or slows it down		Logical
	Cool.	
	The claim says that an object will not move unless a force moves it, and also that an	Generativity

	object will keep moving unless another force stops it.	
Good. You need to address both sides of Newton's first law – what happens when it is not moving and what happens when it is moving. OK, that's the claim. I am saying this is what Newton says, and now we are going to do the rocket balloon lab to try to find out if the book is lying to us or not, or if we can actually prove what he says is true. That is called the evidence. What evidence can we gather through this investigation to either prove or disprove this claim? When you are talking about, let's go back through Chapter 1 and Chapter 2 and begin to develop a list of vocabulary words that you might want to have in your framing that would help explain your position on whether this claim is true of not. Go back into your books and raise your hand if you can think of a word that we might want to use to describe this.		Elaboration Explanation Elaboration Logical Synthesis Elaboration
	Velocity.	Elaboration
Velocity. Now remember what velocity is? That is average speed, but you tell what direction, right. Another one?		Justification
	[reference point]	Elaboration
Oh, very good. The last class didn't get reference point. You don't have to write these yet. Let's just generate them first. More words? Anything that you think is going to help you describe what you think is going to happen with this rocket balloon.		
	Acceleration	Elaboration
Acceleration. Another one?		
	Time.	Elaboration
Yes, you have to have time. Yes?		
	Distance.	Elaboration
Distance. Yes.		Elaboration
	Force.	Elaboration
Force, oh, yeah, we better have that word in there somewhere.		
	Motion	Elaboration
Motion. Any other words that you think might play a part.		
	Energy.	Elaboration
Energy, okay. We said there were two kinds of energy. We haven't focused on them very much, but I'll write them down here – potential and . . .		Elaboration
	Evidence	
Kinetic. Potential and kinetic energy.		
	Mass.	Elaboration
Mass, that is a good one. Yes?		
	Inertia	Elaboration
What is inertia? Does anybody know what inertia is?		
	[All talking at once]	
Good. When this thing is laying right here, inertia says it wants to stay there. It is going to take, in fact, if you have		Justification Elaboration

every tried to push a heavy object, like a car, for example, it takes a lot of energy, but once you get it going, you can get it going. Its inertia wants it to just sit there and do nothing. It is kind of like your big brother who is a couch potato and you can't get him off the couch. Once you get him up and moving, boy, does he get a lot of stuff done. Same thing. The other side of it is, once something is in motion, it wants to continue in motion, unless it is operated on by another force. You think this is a pretty big word for understanding Newton's first law. It is extremely important for you to understand that to understand Newton's first law, because anything at rest tends to stay at rest and that is inertia. Anything in motion tends to stay in motion, that is inertia. It is a good word. Another word?		Generativity Elaboration Explanation Synthesis Generativity Explanation
	Volume.	Elaboration
Volume? You are going to talk about the volume of air in the balloon		Elaboration
	Direction.	Elaboration
Direction, okay.		
	Is another reason the balloon won't stay any longer is because it is not very aerodynamic.	Generativity Justification
Everybody is dealing with the same one, so the only thing we are focusing on is the change in the nozzle length		
	Gravity.	Elaboration
Gravity, thank you. I was hoping somebody would say that word. Am I dealing with a list of vocabulary words that you know their definitions from the work we have done in the last couple of days? If you don't know it, you can easily find it in Chapter 1 and 2? OK. The length of the nozzles.		
	Are we supposed to be writing this down?	
No. The nozzle could be 35, 30, 25, 20, 15 or 10. The first thing you are going to do, remember, you have to tell me what is going to happen. That means which one of these are you choosing. Why do you think it is going to happen? This is extremely important and the why uses these words. The what and the why need to use those words. I want you to get busy now writing up your framing of the investigation. It is going to tell me what you think is going to happen, which one of these is going to fly the longest, and why you think it is going to happen, using as many of these words as you can.		Generativity Justification Explanation
	We are trying which nozzle raises the balloon the highest?	Explanation
No, it is not highest. It is longest hovering.		Explanation
	Is this due?	

This is your rough draft. Eventually you will be writing a final draft that will be turned in, in ink.		
	Is that [mandatory]?	
Yes, it is, or you might take it home and type it. In any case, what you are going to do right now, remember we have three people in a team, and it is perfectly okay if each one of you has a different nozzle length that you think is going to work. Don't share what you think is right. Use your own brainpower and then you can test it against your teammates to see if you are able to think the idea through. This is your 7th year in school and you should be able to put together a sentence that makes sense, that literally states your point of view.		Justification
	Do we have to do this in one sentence?	
You put all of this down and the reason why, that fast?		
	I did it. .	
How many of these words did you use?		
	Not many.	
That's a problem.		
	You are supposed to use almost all of them or as many as you can.	Elaboration
Did you use the words reference point in your description? What is the reference point in this particular lab?		Elaboration
	The reference point is the top of your table	Explanation
Very good. The reference point is the top of your table. You want to be talking about that. Go ahead. Dylan has been kind enough to help us clarify our framing of the investigation. First of all, he says that 20 or 25 centimeter straw will work best. Now, you can't hedge your bets on a hypothesis. I'm sorry. Although it would be nice to do that and it would give you a greater chance to get it right, but you can only chose one distance. If you have chosen more than one, choose the one you want and write it down. You never say, "I think it might be about," you can't do that in this. It will fly best at blank centimeters. That is what it is. If you are wrong, big deal. You learned something from it. There is no way you can say, gee, I hope maybe it could possible be somewhere around the middle of the straw. That doesn't work		Generativity Elaboration Explanation Justification
	But we don't know where you are cutting them at	
Starting with 35 and then 30 and then 25. .		Elaboration

APPENDIX N

Argumentation by Reasoning Complexity

October 26, 2004 *3rd Block, Daily science		
TEACHER	**STUDENT**	**REASON**
You remember your first one. That is when three golf balls and try to determine which one would fly the farthest. We were working on designing the investigation, in which you would have step-by-step directions as to how you would go about doing this. Get a piece of paper and get ready to write it all out now. If you were gone, you will have to do the work. You are expected to write it down as we go over it. Raise your hand if you would be willing to tell us what you have determined is the first thing you are supposed to do. What do you have, first thing?		
	Well, you have to determine the [variables].	
You write down determine the variable, so do you expect the person who is doing the lab to determine the variables or you were supposed to determine the variables? You are? OK, what variable have you determined?		
	I have a couple	
What are they?		
	The golf balls.	Generativity
Did you identify on your first one the three kinds of golf balls you were choosing to use? Or did you say select three different kinds of golf balls? Have you don't that for step one? Don't you think that would be the most important thing to do if you were trying to measure the distance of three golf balls, to say you have to select three golf balls? How many of you did that? A couple of people. There are a lot of people who look like they are not really with us today. Let's join up. You have to select three different kinds of golf balls. Write that one. What do you think would be the next most important thing to put down on your list? Mercedes?		Justification
	What kind of land you are going to have.	Generativity
Somewhere in your description, you should be talking about the surface you are going to be hitting on, right? If you say go to the golf range, that would work. Or go out to an open field or whatever you were going to do. You should tell where you are going to hit. Anything else we need to do?		Justification
	What direction you are	Generativity

	going to hit the ball?	
OK, why would that be important?		
	Because you might hit something.	
If you say it is important to hit the balls south, for instance, why would that be important?		Elaboration
	Then we would know that all the balls are going one way.	Elaboration
What I hear you saying is you want to be sure you hit all the balls in the same direction. You are trying to control the conditions, right?		Justification
	Yes.	
Tessa, did you talk about hit all the balls during the same day, or are you going to hit a Titleist on Monday when it is Sunday with a tailwind and you are going to hit the Top Flight on Tuesday when it is sunny and there is no wind, and you are going to hit the Ben Hogan on Wednesday with a storm coming in and the wind is blowing in your face? Would that affect your results?		Elaboration
	Yeah.	
Good, so you should say there somewhere, hit all the balls at the same time, so that you control the environmental conditions. What else have you got. There is one other real important thing.		Explanation
	Wind?	Generativity
We kind of just talked about that. Anything else you can think of that we need to put down in our designing?		
	How hard it is.	Generativity
Something about the force of the hit, right? We talked about that. We talked about if a machine is going to hit it with the same force or if you are going to use a professional golfer, would he hit it with the same force? Yes.		Elaboration
	What kind of [golf balls].	Generativity
We talked about that already. Yes?		
	What type of club?	Generativity
What kind of club you are going to use, good. What kind of club. If you hit it with a pitching wedge it is going to be a lot different than hitting it with a driver, if you know anything about golf. The driver hits it 250 yards and a pitching wedge hits it 70 yards. That could be a factor. Do you want to talk about how many trials you are going to do? Are you going to hit the ball once? How many times do you think you should hit each ball to make it [fly farther]?		Elaboration
	Three times.	Generativity
Three times she says. Anybody else? Did you say twice? When		Generativity

we were talking about the length of the nozzles, we had 16 trials per nozzle, and we still didn't have very consistent results. More trials is always better than fewer trials. With golf balls, that is not every hard to do, is it? Do you think it would be very hard to have each golf ball hit 25 times? Would that be very hard to do? You could do that in an afternoon, couldn't you, pretty easily? Think about the number of trials. Look over your answers, and see if there is anything that you want to add, and if there isn't, in the margin, say "see back," and then add whatever you want on the back of the piece of paper. Take a couple of minutes to look this over and make sure you have this done the way you want it. The reason this is important, ladies and gentlemen, is we have done designing the investigation with the rocket lab (?). We have three of them here on this daily science. I've decided just to grade the rocket lab, to make it worth, like 40 points – 10 points for each section. The next lab we are going to do, you are going to be assessed. It is going to go in your portfolio on two dimensions – designing the investigation and collecting and presenting knowledge. That is going to go in your portfolio, so we need to get good at this skill. Day two was the one about the bean plants. You were asked to talk about the things that were controlled in this experiment. Preston, what was one thing that was controlled in this experiment?		
	The sunlight.	Generativity
The sunlight was not controlled.		
	The water.	Generativity
The water was controlled.		
	Was [controlled].	
That wasn't controlled. What was controlled? Austin?		
	The putting it in the pot.	Generativity
We have the pots was the same, the soil was the same, water was the same and what?		
	Fertilizer?	Generativity
The fertilizer was the same. They controlled those variables and I asked you on this one to tell me what things were controlled. Randy, what was the thing that was wrong with this experience?		
	You couldn't control the sunlight outside.	
We didn't know if it was the plant growing higher or it was because the light wasn't controlled. That was the thing that was wrong, correct? Yes?		
	And because there were two different types [friction].	

We don't know if it was the plant that grew faster, or if it was the light that caused it to grow faster. We had two things going on. We had two variables going on rather than only one. Remember, you can only test one variable at a time. If you try to do more than that, things don't work. That is true in a controlled experiment that you do in a lab. When you get out there in the field and try to do a lab, there are so many things going on, it is really had to control all the variables in the natural world. Those experiments can be a little bit more loose. Day three is around here somewhere. This one we tried to identify different types of energy that we had in the classroom. That is when we were looking at energy, wasn't it, upside down and backwards. We thought we were in a parallel universe there for a second. Can you think of one kind of energy that you got on your list?		
	The water	Generativity
How are we using the energy of the water in this room? Do we have a little electric generator going on in here and we are running water through it.		Justification
	I said the wire.	Generativity
Wire? Electricity, yes. So electricity is one type of energy. What is another one? You didn't write any of them down, and you even got to brainstorm with your own team? Casey?		Elaboration
	Sound?	Generativity
Sound energy, good. We have waves, don't we? What other types of waves do we have in here?		Justification
	Static.	Generativity
Static energy, I guess, if you run back and forth on the chair, you could collect some static electricity.		Explanation
	Body heat?	Generativity
Body heat is a good one. That is a good one. Another one, Harrison?		
	Natural?	Generativity
Natural as opposed to artificial energy?		Elaboration
	A person might [have energy].	
We have energy from people, the heat. We have sound energy. We have electrical energy. What else?		Justification
	[solar energy]	
We have life energy from the sun, radiant energy.		Generativity
	Radio waves	Generativity
Yes, there is radio energy passing through us right now. TV energy. There is probably energy from somebody's cell phone. Those really aren't up here. Here is what they came up with. Sunlight, electricity, ocean of you moving around, heat, not only from you but in the room, there is heat energy coming out of these ducts, right. Sound energy. You were asked to have two of those down. Our last one is the one we attempted to do yesterday, and it was kind of a hard one. Let's talk about it a little bit here. [design]		Elaboration

experiments [to determine who is] the fastest boy and girl in class. Jesus, what did you say you should do first?		
	Control the variable.	
What variable were you going to control?		
	The time and the length.	Generativity
The time and the length. Now you are designing your investigation and the person is reading it, and they want to know how to do that. What is the first thing you have told them they have to do?		
	Set up a chart?	
Set up a chart. The very first thing you are going to do is set up a chart so that they can record what?		
	The trials.	Generativity
The trials are going to be what?		
	[how far]	
How far do you have them going?		
	A mile.	Generativity
OK, so one of the first things you are going to do is have every person in the room run a mile.		Elaboration
	Yes.	
And time them? Alright. So your experiment is who is the faster miler in the classroom, right? Who else now has come up with other things? Harrison?		
	I said you could have each boy and girl run around the track [each] twice, record the average time	Generativity
The distance of your trial is 400 meters around the track. Yes?		Elaboration
Crystal here is saying that the important think is also identifying how many trials you are going to do. Jesus is going to require his people to run the mile more than once?		Generativity
	Yeah.	
Maybe give them a couple of day's rest. OK, we are talking about the same things we were talking about with our Daily Science 1. How many trials are you going to do to get enough evidence to make sure you are right. How far as they going to go or how many times are they going to do it. Has anybody talked about anything else you were trying to control? Harrison?		
	The surface they were going to run on.	Generativity
The service they were going to run on. Were they running around the track or are they going to run a cross-country course?		Elaboration

Are they running up a hill?		
	How many people are running at time?	Generativity
How many people run at a time. You can talk about individuals running and timing them or you could run a group and then whoever won that race would then run against the winner of the next race, and all that kind of stuff, right? Anybody talk about whether they should all wear [inaudible] clothes or they should all run in jeans, or they should all run in a swimming suit? Did you talk about controlling that variable? Do you think that would make a difference?		Elaboration