Developing Explanations: Student Reasoning about Science Concepts during Claims-Evidence Inquiry Lessons

AN ABSTRACT OF THE DISSERTATION OF

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Recent science education reforms have placed a large emphasis on inquiry-based teaching strategies as an effective way of improving conceptual understanding of science principles, comprehension of the nature of scientific inquiry, and development of the abilities for inquiry (NRC, 1996). To better understand the relationship between inquiry-based instruction and student learning, this study examined the nature of student reasoning about science concepts during Claims-Evidence Inquiry lessons. The Claims-Evidence approach to inquiry teaching was chosen as the context for this study, because it focuses student investigations on specific scientific concepts. It uses a deductive approach to question generation, in which scientific claims are used as springboards for student investigations (Gummer, 2002; Thompson, 2003; Briley, 2003).

This study found that the Claims-Evidence Inquiry model provides a framework for encouraging student reasoning about science concepts by providing supports for the development of explanations. Students were encouraged to develop explanations and consider how science concepts related to their investigations. A number of instructional factors appeared to influence students' development of explanations during Claims-Evidence inquiry. These included explicitly encouraging explanations, clarifying the connection between the claim and the investigation, the presentation of the claim, the nature of the claim, the development of science concepts, the design of the task, and the development of inquiry skills.

Students were found to engage in discourse related to explanations during all four phases of the inquiry; forming a question or hypothesis, designing an investigation, collecting and presenting data, and analyzing results. Most of the verbal discourse related to explanations occurred when students were reasoning about hypotheses and

most of the written discourse related to explanations occurred when students were reasoning about hypotheses and results. This analysis also identified three primary types of explanations utilized by students: analogical explanations, systems-based explanations, and concept-focused explanations. Analysis of the reasoning used in written explanations for results highlighted issues related to the application of the science concepts, explicit links between variables in the investigation and the science concepts, and the nature of the causal reasoning used in explaining results.

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Chair of the Department of Science and Mathematics Education

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Jerine M. Pegg, Author

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THE PROBLEM

Introduction

Recent science education reforms have placed a heavy emphasis on inquiry-based teaching strategies as an effective way of improving conceptual understanding of science principles, comprehension of the nature of scientific inquiry, and development of the abilities for inquiry (NRC, 1996). The current emphasis on inquiry instruction suggests that inquiry teaching should be a central component of science instruction and a primary means of educating students about disciplinary science content. These arguments are based on theories of learning which emphasize the importance of direct experience and active engagement for meaningful learning (Bruner, 1960; Piaget & Inhelder, 1969; Driver et al., 1985) as well as social constructivist theories of learning (Schunk, 2000) that emphasize the importance of interactions among students, their teachers, and their peers.

Understanding the relationship between inquiry teaching and student learning of disciplinary science concepts requires an examination of specific models of inquiry teaching, how they are implemented in the classroom, and the student reasoning that occurs in that context. This study examined the Claims-Evidence model of inquiry teaching that focuses student investigations on the underlying science concepts that are targets of instruction while fostering an understanding of the role of inquiry in developing those concepts.

Scientific Inquiry

Scientific inquiry can refer to the work of scientists, a learning goal for students, or a teaching method (NRC, 1996). The National Science Education Standards (NRC, 1996) include content standards for Science as Inquiry, which include both abilities and understandings of inquiry. Abilities necessary to do scientific inquiry include things such as identifying questions that can be answered through scientific investigations, designing and conducting scientific investigations, and developing explanations, predictions, and models using evidence. Understandings about scientific inquiry include understandings about how scientific knowledge is developed and subsequently change as a result of new evidence and interpretations of evidence.

In addition to inquiry as a set of learning outcomes for students, the National Science Education Standards (NRC, 1996) also define a set of science teaching standards that emphasize inquiry as a central component of science teaching. Scientific inquiry as a teaching method refers to the instructional strategies used by teachers to engage students in learning about science and science content through the process of scientific inquiry. The National Science Education Standards see inquiry teaching as an important method of teaching students science concepts in addition to teaching students' abilities and understandings about scientific inquiry (Bybee, 2004).

Although inquiry-based instruction has been a focus of both national and state reform efforts, teachers are sometimes reluctant to use inquiry-based instruction when they feel they need to "teach the content" (e.g. Gallagher and Tobin, 1987; Kemper 2004). For some teachers, this is due to the extra time that they feel that inquiry instruction takes relative to other instructional methods for teaching the content, especially when teachers feel pressure to prepare students for high stakes exams (Trautmann, MaKinster, & Avery, 2004). For other teachers, skepticism about the influence of inquiry instruction on students understanding of science content makes them unwilling to invest the time into this mode of instruction. Westbrook (1997) suggests that many teachers do not see the laboratory as a "source" of instruction and struggle with how to meld labs with students' constructions of content. Furthermore, she suggests that "If experimentation were viewed as being a source of true understanding of content, rather than a time and money consuming attempt to 'play scientist', teachers might be more willing to invest themselves and their students in active investigations" (p. 13).

Instructional Scaffolding and Teacher Discourse during Inquiry

The role of the teacher in structuring inquiry lessons and in guiding student discourse is a key component in students' construction of meaning during inquiry investigations. As Metz (2004) states, "a curriculum can structure an activity, but the subsequent scaffolding of student thinking can never be fully scripted." Analysis of teacher discourse during inquiry has found that the strategies that teachers use can vary widely among teachers and between different types of activities (Tzou et al., 2002) and influences the degree to which student investigations focus on scientific concepts and the construction of new understandings. The decisions that teachers make during inquiry lessons often involve a number of trade-offs, for example, trade-offs between developing students' ideas versus explaining formal theories (Sandoval et al., 1999) or between encouraging exploration or establishing procedure (Tzou et al., 2002). These decisions are complex and are likely to be significant influences on student learning during inquiry.

Student Discourse during Inquiry

Previous research on scientific inquiry has found that students seldom engage in discourse about the scientific ideas underlying their investigations. During small group work student discourse often focuses more on group processes and products rather than on scientific ideas (Bianchini, 1997; Shepardson, 1996; Krajcik et al., 1998). Studies that have looked at specific aspects of student inquiry investigations suggest that the questions students generate, their data collection methods, and their analysis of that data are likely to influence the degree to which their investigations lead to deeper understanding of the science concepts they are investigating (Krajcik et al., 1998; Scardamalia & Bereiter, 1992). Studies of argumentation in inquiry-based lessons have found that students make few claims as they engage in inquiry investigations and often use inadequate evidence to support their claims (Watson, Swain, & McRobbie, 2004; Sandoval, 2003; Sandoval and Millwood, 2005).

The Role of Explanations in Inquiry

The development of explanations supported by evidence is a key aspect of scientific inquiry (NRC, 1996). In the document *Inquiry and the National Science Education Standards*, the National Research Council (2000) identifies 5 essential features of classroom inquiry. Four of the five essential features emphasize the importance of explanations.

Essential features of classroom inquiry (NRC, 2000; emphasis in original)

- Learners are engaged by scientifically oriented questions.
- Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate **explanations** from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Learners communicate and justify their proposed explanations.

The goal of science is to construct, evaluate, and refine explanatory models (Duschl, 1990). However, recent critiques of science education have suggested that instruction often focuses on the processes of experimentation and data gathering, while deemphasizing the construction of meaning and argumentation (Newton, Driver & Osborne, 1999).

Research on students' explanations has attempted to identify the types of explanations invoked when reasoning about natural phenomena (Solomon, 1986) and the nature of the causal reasoning implicit in scientific explanations (Grotzer, 2003). Research on explanations related to teaching has focused on supporting students and teachers to develop argumentation practices (Osborne, Erduran, and Simon, 2004a; Zembal-Saul, 2005) and the development of curriculum that focuses on explanation-driven inquiry (Kuhn & Reiser, 2004; Sandoval & Reiser, 2004; Duschl 1990; Toth et al., 2002).

Claims-Evidence Model of Inquiry

Claims-Evidence is an inquiry-based instructional strategy that uses a deductive approach to question generation, in which scientific claims are used as springboards for student investigations (Gummer, 2002; Thompson, 2003; Briley, 2003). The claims may be scientific theories, laws, or hypotheses. Instead of providing students with a question for investigation or having students generate their own questions based on a specific topic or a topic of their choosing, the Claims-Evidence model focuses student questions and investigations on scientific claims. In the Claims-Evidence model students are encouraged to consider how their questions, procedures, and conclusions relate to the claim they are testing. This encourages students to link their evidence and explanations to the underlying science concepts rather than merely stating whether their data supports their hypothesis or not.

Summary

The Claims-Evidence Inquiry Model provides a useful context in which to examine students' development of explanations during inquiry because the theory that the students are using as a framework for designing their investigations and explaining results is made explicit. Examining student explanations within this context can provide insight into the nature of causal reasoning that students employ when developing explanations. Furthermore, examination of student explanations can highlight areas of student difficulty and suggest areas in which instruction may need to provide additional supports in order to assist students in developing explanations from inquiry investigations.

Statement of the Problem

Teachers' concerns about the use of inquiry to teach content and the complex relationship between aspects of inquiry instruction and student learning of science content is fueling a field of research examining specific models of inquiry-based instruction, such as Claims-Evidence. This study investigated the factors influencing student learning of science content during inquiry-based instruction. Specifically, this study examined the use of the Claims-Evidence model of inquiry instruction. Anecdotal accounts from teachers suggest that the Claims-Evidence model is an effective approach for teaching content through inquiry (Briley, 2003; Thompson, 2003) which suggested the need for a formal study examining its use in the classroom and its effectiveness at improving student understanding of science content.

Understanding the influence of inquiry instruction on student learning requires a deeper look at the development of student explanations during inquiry and the aspects of inquiry instruction that facilitate and hamper students' development of scientific explanations. This research examined the relationship between inquiry-based instruction and student learning of science concepts during Claims-Evidence inquiry using an analytic framework based on student explanations.

In summary, this study addressed four main questions:

1. What aspects of instruction influence student's engagement with the science concepts and their ability to link claims to evidence?
2. Where in the inquiry cycle do students invoke explanations and what is the nature of those explanations?
3. What is the nature of student reasoning when explaining the relationship between the results and the claim?
4. What changes occur in student understanding of science concepts as a result of engagement in Claims-Evidence inquiry lessons?

Significance of the Study

The Claims-Evidence approach to inquiry is currently being promoted throughout the state of Oregon as a means of teaching content through inquiry. This study examined how this approach is currently being used and its influence on student learning of and reasoning about disciplinary science concepts.

It has been argued that inquiry instruction is an effective means of increasing student understanding of science concepts. However, few studies have specifically examined what aspects of inquiry instruction lead to increased science content understanding. Inquiry instruction is multidimensional and can take many forms. Both student behaviors and teacher behaviors can affect the influence of inquiry instruction on student learning. The examination of students and teachers engaged in inquiry instruction during this study provides insight into what types of scaffolding might assist students in developing explanations which support them in making connections between the inquiry investigations they are conducting and the scientific content they are learning.

Some studies have provided insights into the relationship between aspects of the inquiry process and student science learning by analyzing the teaching of inquiry (Krajcik et al, 1998; Roth and Roychoudhury, 1993). However, in these studies disciplinary-specific content understanding was not a specific focus of the investigation and was not examined in depth. Other studies have provided detailed descriptions of student understanding of disciplinary science concepts before and after participating in inquiry investigations (Eilam, 2002). However, these studies have not specifically examined what aspects of the inquiry process supported and/or hindered this understanding. This study specifically examines this link and provides needed information about the relationship between students' development of explanations and instruction during inquiry.

Most of the previous studies conducted on inquiry instruction (Krajcik et al., 1998) have involved inquiry curriculum designed by the researchers and carried out by the teachers. Keys and Bryan (2001) pointed out "more research is needed on teacher-designed approaches to inquiry-based instruction, as well as teacher-designed adaptations of curriculum to their own unique situations." This study addresses that need by examining inquiry investigations that are designed by the teachers and carried out in regular classrooms.

CHAPTER II

LITERATURE REVIEW

Introduction

This chapter explores the literature related to inquiry instruction and its relationship to student reasoning about science concepts during inquiry. The discussion is organized into four sections. First, inquiry instruction is discussed by presenting a brief history of inquiry teaching, the theoretical framework for inquiry in science education, and a description of inquiry teaching in Oregon. Second, studies of instructional influences on inquiry are examined including instructional scaffolding of inquiry lessons and teacher discourse during inquiry. Third, student reasoning about science concepts during inquiry is discussed in relationship to student discourse about science concepts, the role of explanations, and the nature of causality in student explanations. Finally, the Claims-Evidence Inquiry model is described.

Inquiry Instruction

Defining Inquiry

Synthesizing research on inquiry-based instruction is difficult, because inquiry is defined differently by different researchers and is referred to by various names (Anderson, 2002; Minner, D. D., Levy, A. J. Century, J. R., 2004). The definition of inquiry from the National Science Education Standards (National Research Council, 1996) was used as a starting point for identifying research on inquiry-based instructional strategies. In the Standards, inquiry is defined as “a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results” (p. 23).

However, not all inquiry instruction will contain every component of this definition. This analysis includes studies that contain aspects of this definition, consistent with the framework for describing inquiry instruction developed by the Center for Science Education (Minner, D. D., Levy, A. J. Century, J. R., 2004). In the CSE framework, studies were considered to pass the "inquiry threshold" if there was at least some emphasis on any element of the inquiry domain in any component and science content was explicitly taught. The inquiry components included question development, design of investigations, data collection, development of conclusions, and communication. Inquiry teaching is complex and multifaceted and examinations of studies of inquiry teaching must take into account the variability and range of practices that fall under the umbrella of inquiry.

History of Inquiry Teaching

Engaging students in the processes of scientific inquiry in order to better understand the concepts and processes of science has a long history in science education. In the 19th century, science began to be incorporated as a regular part of the school curriculum and advocates of science education argued that the science laboratory and student investigations were an important part of learning about science. De Boer (2004) cites writings as early as 1864 by Herbert Spencer that argue that science laboratories should be used to allow students to directly observe natural phenomena and to provide practice in drawing conclusions from data. According to Spencer (1864), "Children should be led to make their own investigations, and to draw their own inferences. They should be told as little as possible and induced to discover as much as possible" (pp. 124-125).

In the first half of the twentieth century inquiry-based instruction tended to focus on teaching students scientific ways of thinking and engaging students in problems that had personal or social relevance. Dewey (1910) argued that science was more than a body of knowledge to be learned, but that it was a process and method as well. Starting in the 1950's there was a curriculum reform movement that focused on teaching students the fundamental ideas of the disciplines in a way that mirrored the way scientists generated new knowledge. During this time there was a greater emphasis on making instruction as close as possible to actual scientific inquiry. Joseph Schwab (1962) encouraged the use of inquiry teaching as a way of increasing the number of students that were qualified to go into scientific and technical fields and as a way of educating the public in order to increase support for scientific research. Schwab argued that students should learn science through active engagement in the process of inquiry and that laboratory work should precede formal explanation of science concepts. The launching of the sputnik satellite in 1957 raised public awareness of the quality of science education and spurred the development of a variety of inquiry-based curriculum materials, including the so called "alphabet" curricula such as the Biological Science Curriculum Study (BSCS), Intermediate Science Curriculum Study (ISCS), and Science - A Process Approach (SAPA) to name a few (Shymansky, Kyle, & Alport, 1983).

By the 1970's the focus shifted once again to educating a citizenry that would have the skills to function effectively in a scientific world. Student investigations focused on answering questions that students dealt with in their everyday lives rather than on basic concepts and principles of science. Scientific inquiry was often taught in the context of science-related social problems such as in the science, technology and society (STS) curriculum (Ramsey, 1997).

At the end of the 20th century science education documents recognized a variety of arguments for inquiry teaching, including educating students about the nature of science, contributing to students' intellectual development, and improving students' ability to solve everyday problems. In addition, current arguments for inquiry teaching suggest that it is a more effective instructional approach for teaching science concepts and principles (NRC, 2000). The National Science Education Standards (NRC, 1996) include content standards for Science as Inquiry, which include both abilities and understandings of inquiry. In addition to inquiry as a set of learning outcomes for students, the National Science Education Standards also define a set of science teaching standards that emphasize inquiry as a central component of science teaching. Scientific inquiry as a teaching method refers to the instructional strategies used by teachers to engage students in learning about science and science content through the process of scientific inquiry.

Theoretical Framework for Inquiry in Science Education

Much of the current argument for inquiry teaching is based on a synthesis of research on learning, including work by Piaget, Bruner, and Vygotsky. Piaget's theory of development suggests children's reasoning progresses through distinct stages of development and that movement through these stages is dependent upon the processes of assimilation, accommodation, and equilibration (Piaget & Inhelder, 1969). His developmental stages include – sensorimotor (0-2 years), preoperational (2-7 years), concrete operational (7-11 years) and formal operational (11-16 years). Piaget (1964) describes conceptual development as a process of children discovering and making sense of the world through experience and reorganization of mental structures. At each stage of development the child actively engages in a construction of reality. Piaget saw development and movement through the stages occurring when students experienced disequilibrium between what they understood and what they observed. Equilibration occurs when children are able to integrate this new knowledge of the world into their conceptual structures. Hands-on activities were seen as necessary for providing students the opportunity to resolve discrepancies between what they know and what they experience. This would then lead to equilibration and the accommodation of new concepts. According to Piaget, this cannot be imposed from outside, but must come from inside the student.

Piaget's developmental stages also suggest that students in the concrete operational stage need the opportunity to interact with hands-on materials before creating abstract conceptual understanding. Although Piaget identifies the concrete operational stage occurring between the ages of 7 and 11, a study by Lawson and Renner (1974) found that a majority of American high school students still function at the concrete operational stage. Piaget's theories of development offer a rationale for emphasizing the use of laboratory-based activities in science instruction.

The work of Jerome Bruner also supports the idea that active learning is important for student understanding of concepts. According to Bruner (1960), learning is viewed as three simultaneous processes including the acquisition of knowledge, the transformation of knowledge, and the check of the pertinence and adequacy of knowledge. Bruner (1960) argued, "learning attained through discovery is more meaningful than that from rote memorization”. He suggested that the benefits of discovery learning included an increase of intellectual potency, a shift from extrinsic to intrinsic rewards, learning of heuristics of discovery, and an aid to conserving memory (Bruner, 1962). Although inquiry teaching is now conceptualized as more than discovery learning, the work of Bruner provided an essential framework to the idea that meaningful learning could occur through students’ engagement with phenomena rather than through instruction focused on lecture, memorization, and verification.

An important component of inquiry teaching involves discourse that students engage in with other students and with their teacher during inquiry investigations. Social constructivist theories of learning (Schunk, 2000), including the work of Vygotsky suggest that learning is not only an individual process, but that it is also developed through social interactions, which are socially and culturally mediated. Vygotsky’s work suggests that it is not only the interactions that occur between students and their environment that is important, but also the interactions that occur between students and their teachers and peers. Inquiry teaching provides a context in which students can engage in discussions that “set the stage for the students’ construction and reconstruction of science concepts” (p. 14) (Westbrook, 1997).

Recent research on learning (Bransford et al., 2000) has also provided insight into the ways that children acquire new knowledge and the types of knowledge and abilities that are important for successful performance and application of knowledge. Research on students’ conceptions of science suggests that students develop conceptions about natural phenomena throughout their life and that these conceptions influence their learning (Driver, Guesne, & Tiberghiem, 1985). Students build new knowledge and understanding on what they already know and believe and students “prior” beliefs are often inconsistent with “scientific” ways of viewing the world. These preconceptions are often entirely reasonable based on students’ observations of the world around them and are therefore often resistant to change, particularly using conventional teaching strategies (Wandersee et al., 1994).

Studies of experts and novices suggest that people who have expertise in a field not only have acquired a great deal of content knowledge, but that that knowledge is organized in ways that reflect a deep understanding of the subject matter (Bransford, et al., 2000). The organization of this knowledge allows experts to easily retrieve and apply this knowledge. Studies of expert knowledge also suggest that in order for their knowledge to be useful, they must know the contexts in which the knowledge is applicable in order to transfer that knowledge from one context to another. This research suggests that it is important for students to have a deep understanding of the discipline and of the relationship between the concepts within that discipline. However, students must also develop the abilities necessary to apply that knowledge in appropriate contexts. Many of the current science education reform documents argue that inquiry teaching provides a context for students to actively engage with natural phenomena and develop new knowledge in a manner that is consistent with the learning theories described above.

Inquiry in Oregon

Inquiry teaching has received a lot of emphasis in Oregon due to the inclusion of inquiry standards and scientific inquiry classroom-based performance assessments. In 1996 the Oregon Educational Act for the 21st Century created content standards for every subject. The Oregon Science Content Standards include standards for scientific inquiry along with standards in life, physical, and earth science. Scientific inquiry standards include abilities necessary to conduct scientific inquiry and understandings about the nature of scientific inquiry. Students' disciplinary content knowledge is assessed by standardized multiple-choice knowledge and skills tests and inquiry abilities are assessed by classroom work samples.

Students are required to complete scientific inquiry work samples at least once each year in grades 4-10. Classroom work samples are developed by the teachers and are integrated into daily classroom activities rather than acting as a stand-alone assessment. Teachers score the work samples using the Oregon Scientific Inquiry Scoring Guide (Appendix A). The scoring guide is composed of four dimensions; Forming a Question or Hypothesis, Designing an Investigation, Collecting and Presenting Data, Analyzing and Interpreting Results. The primary focus of the scoring guide is on inquiry skills. However, components of the scoring guide do require students to accurately use scientific knowledge. At the 8th grade level, the Forming a Question or Hypothesis dimension requires students to use scientific knowledge as background information in order to get a

5 or 6 on the scoring guide. On the Analyzing and Interpreting Results dimension, students in 8th grade must "use scientific terminology with minimal errors to report results and identify patterns, and attempts to propose explanations" in order to get a passing score.

Implementation of this assessment has been gradual. In 2003-04 students at grade 8 were only required to report scores on the collecting and designing dimensions. By 2005-06 they were required to report scores on all four dimensions. Although teachers are required to have students do one scientific inquiry work sample per year and report their scores on them, there are no consequences from the state if they do not do one or if they do not pass. However, many teachers have included the inquiry work samples as required components of grades for their courses.

For the past four years, the Oregon Department of Education and the Oregon Science Teachers Association have put on workshops that support teachers to develop classroom-based inquiry tasks that can be scored using the State Scoring Guide. To assist teachers in developing inquiry tasks, the Claims-Evidence model of inquiry instruction was introduced to teachers during the second year of the workshops as a framework for structuring inquiry tasks.

Instructional Scaffolding and Teacher Discourse during Inquiry

When implementing inquiry-based instruction, teachers have a number of decisions to make about how they structure activities and engage in discourse. These decisions influence whether the focus is on science content, science process, or community building. Analysis of teacher discourse during inquiry has found that the strategies that teachers use can vary widely between teachers and between different types of activities.

One decision teachers must make is how much the inquiry will consist of student-led discussions and how much will be led by teacher-guided discussions. A study by Hogan et al. (2000) examined the nature of student discourse during peer and teacher guided discussions during a 12-week inquiry-based unit in which students constructed and tested mental models of the nature of matter. The teacher-developed instructional unit differed from most inquiry-based instruction in that it emphasized theory building, rather than experiment planning and data generation. The main goals of this unit were to provide an experience in the process of building models and theories as scientists do, more than as providing a solid conceptual foundation in the nature of matter. Examination of discourse within student groups found that groups differed widely in the amount of conversation they dedicated to discussing the nature of matter and that some groups were more able than others to engage in productive dialogue. This study also found that the nature of the dialogue differed between teacher-guided discussions and student-guided discussions. Teacher-guided discussions were a more efficient means of attaining higher levels of reasoning and higher quality explanations, whereas peer discussions tended to be more generative and exploratory. Both of these types of discussions can be valuable and teachers must determine how to navigate between these two contexts.

A study by Sandoval et al. (1999) examined the use of whole class discussions as a vehicle for connecting students understanding to formal domain theories. This study focused on the BGuILE curriculum and examined how teachers used whole class discussions to connect students' independent and small group work during computer-based inquiry with specific conceptual understandings the targeted by the curriculum. This curriculum included two computer-based investigations of topics related to natural selection. The discourse strategies and activity structures for two teachers using the BGuILE curriculum were examined.

One teacher used what the authors referred to as *problematized explanation dialogues* in which he engaged in extended dialogues with a single student in order to construct an explanation for some evolutionary phenomena. These dialogues encouraged the student to construct and defend explanations for novel phenomena related to the topic of study. In contrast, the discourse strategies of the second teacher consisted primarily of what the authors termed *debriefing discussions* in which the teacher used whole group discussions to make sure that students had gotten what he had hoped they would from the activity. The second teacher's discourse involved leading questions that appeared to be guiding students step-by-step towards a particular explanation. The questions used by this teacher were primarily *fill-in-the-blank questions* or *assent questions*. This teacher also tended to directly challenge incorrect responses rather than probe for further explanation as was seen in the discourse of the first teacher.

Sandoval et al (1999) suggest that teachers' discourse strategies may be a consequence of the trade-offs between student knowledge generation and concept development that the teachers are negotiating in these inquiry-based activities. They identify five dimensions of trade-offs.

- Developing students' ideas vs. explaining formal theories
- Exploration of content vs. review grounded in prior activity
- Student vs. teacher-directed discussion
- Teacher as authority vs. teacher as more expert guide
- Few students participate in depth vs. many students participate briefly

This study highlights how these trade-offs can influence the discourse strategies used by teachers during inquiry. The choice of discourse strategies may also influence students' opportunity to learn. However, the authors are cautious not to place judgment on the efficacy of either teachers discourse strategies. The authors point out that more research is needed on the relationship between different discourse strategies and student learning.

Other examinations of teacher behaviors during inquiry have also described how the dilemmas that teachers face during inquiry teaching influence the strategies that teachers use in various inquiry activities. Tzou et al. (2002) examined the strategies used by two middle school teachers during the implementation of Struggle for Survival, a computer-supported inquiry curriculum on natural selection. This study examined the teachers' practices across multiple activities and found that the strategies they used varied between teachers and between activities.

Analysis of videotaped observations of two teachers, Ellen and Paul, revealed 5 main types of strategies used by the teachers. These included structuring, revoicing, probing, expanding, and modeling. In addition, each of these strategies was used in multiple ways. For example, the structuring strategy could involve structuring around content or structuring around procedures. The revoicing strategy was used to revoice in students' own words or to revoice in order to introduce scientific language. Examination of two activities used by Ellen found that the strategies she used varied widely across these two activities. In an initial brainstorming activity, Ellen primarily used probing for articulation and revoicing in students' own words strategies. However, in a graphing activity Ellen primarily used a structuring around procedure strategy and only minimally engaged in probing students to expand. It appears that in the initial brainstorming activity Ellen seemed to prioritize community over process which was reflected in her strategies that focused on including all students in the discussion and valuing their ideas. However, in the graphing activity, the dilemma appears to be one between encouraging exploration and establishing procedure. Her strategy in this activity largely focused on having students understand the correct procedure.

A comparison of the two teachers' strategies during the brainstorming activity suggests how teachers' priorities influence strategy use when faced with instructional dilemmas. In contrast to Ellen's focus on valuing student ideas through the use of probing for articulation and revoicing in students' own words, Paul primarily used strategies involving structuring around content. Paul used the brainstorming activity to focus students on the specific disciplinary content areas that they will be covering and the content involved in identifying what an acceptable hypothesis is. In general Ellen's strategies were representative of her priority of building community in her classroom by including student ideas and voices in the discussion, whereas Paul placed more of a priority on the "grounding in content" dimension of inquiry than of the "building community" dimension.

The authors suggest that the variation seen in the teachers' practices is a result of a series of dilemmas among different aspects of practice. These dilemmas influenced what gets foregrounded and what gets backgrounded depending upon the structure of the lesson, the content or procedural demands of the lesson, the teachers' perceptions of students' abilities, the time demands of the lesson, or the teachers' priorities for the lesson.

Understanding the relationship between inquiry-based instruction and student learning of disciplinary science content requires more than examining the nature of the curriculum that is being implemented. It requires examination of the types of activities and discourse strategies applied by teachers. The studies above suggest that the types of strategies that teacher's use when engaging in discussions with students during inquiry may have an influence on the understanding of the science content that students construct. However, none of these studies directly examined this relationship.

Student Reasoning about Science Concepts during Inquiry

Student Discourse about Science Concepts during Inquiry

Previous studies of student behaviors during inquiry suggest that students often fail to connect their inquiry investigations to the underlying science concepts. Studies that have examined group work during science have generally found that students seldom engaged in discourse about the scientific ideas underlying their investigations. Instead, student discourse often focused more on group processes and products rather than on scientific ideas (Bianchini, 1997; Shepardson, 1996; Krajcik et al., 1998; Jimenez-Aleixandre et al., 2000).

In a study of classroom discourse in a high school genetics class, Jimenez-Aleixandre et al. (2000) found that the exchanges between students focused primarily on procedure or school culture rather than the stated learning goals. They termed this “doing school” or “doing the lesson” versus “doing science”. However, they did note that as discussion proceeded, the contributions of students related more to the science issue and less to rules or to incidental talk. Talking science seemed to be most prevalent during whole-class discussions.

Shepardson (1996) examined the nature of small-group social interactions and its relationship to children’s science learning during a 15-day unit on insect life cycles in a first grade classroom. This study examined interactions between the teacher and students and between students and other students. Students’ interactions with each other during small group work tended to focus on negotiating actions and sharing materials. None of the discussions between students during the small group work was identified as negotiating meaning relating to their investigations. Interactions between the teacher and students focused on negotiating status, actions, and meanings. Teachers’ interactions with students when negotiating meaning almost always occurred with individual students and did not encourage interactions between students. Analysis of pre- and post-instruction interviews that probed the students understanding of insect life cycles found that students constructed understandings as a result of engagement in these activities and the teacher's individual assistance with their knowledge construction.

A study by Bianchini (1997) examined knowledge construction during small group activity in a middle school life science classroom. The activities examined in this study involved varying levels of inquiry. However the conclusions appeared to be consistent across different types of activities. Analysis of student discourse during the small group activities found that students rarely discussed scientific ideas or applications. Students appeared to place priority on accomplishing the procedural aspects of the task, such as conducting the experiment, building a model, or writing a skit, rather than examining the key concepts that the tasks were meant to address. Although the tasks were often focused on an overriding conceptual question, such as "why do we breath?" the procedural aspects of the task often required the majority of the students' attention, which diminished opportunities for the students to discuss the content or explore additional avenues of investigation. In addition, the students often ran out of time to complete the aspects of the task that would have encouraged them to more deeply examine the conceptual aspects of the content. For example, one group spent the majority of their time dealing with the procedural aspects of their investigation and they were left with only 30 minutes to organize their results, write their individual reports and prepare for their presentation.

Another study of middle school students engaged in long term inquiry projects specifically examined the nature of student behavior during the different phases of the student investigations. Krajcik et al. (1998) examined eight middle school students as they designed and carried out their own investigations over several months. In the first project, students investigated what kinds of materials decompose and what factors affect decomposition. In the second project, students generated a question about water or its uses. Videotaped observations, artifacts, and student interviews were analyzed with respect to (a) thoughtfulness with respect to content and self regulation, (b) group process with respect to managing interactions and dividing responsibilities, and (c) motivation. This analysis was used to create a summary of how each student engaged in each aspect of inquiry (e.g., asking questions, designing investigations, carrying out investigations, analyzing data and drawing conclusions, and collaborating and presenting findings).

The analysis of this study was not specifically focused on the relationship between inquiry teaching and content understanding. However, findings from the study suggest aspects of the inquiry process that allowed students to explore scientific ideas and highlights areas that were problematic in terms of students' connections between inquiry and content understanding. It is important to note, however, that interpretation of student understanding was primarily based on analysis of written artifacts, such as notebooks, reports, and presentations; and investigators were unable to follow up with individual interviews or tests to tap conceptual understanding. Therefore, the findings may underestimate the quality of student content understanding.

The authors' analysis of the first aspect of inquiry, asking questions, suggests that the students posed questions that were worthwhile, although of variable quality. In general, the authors found that students' investigations of these questions allowed students to explore key scientific areas related to curriculum goals. However, not all the questions students generated were rich enough to encompass the content the teachers had selected. In addition, student questions sometimes stemmed from personal interest or uniqueness of the question rather than any specific connection to the scientific content of the driving question. For example, one group explored the question "When there is water in one bottle and apple juice in another bottle which decomposition column decomposes faster?" Apple juice was chosen because they liked apple juice not because of any scientific reason for comparing water and apple juice.

Student discussions about the designs of their investigations focused primarily on feasibility and procedures. Students' lack of knowledge about the question they were asking sometimes hindered their ability to develop an appropriate design to test out their ideas. In designing investigations, especially qualitative ones, students did not always identify what they were looking for. In addition, they often included measures with which they were familiar, but that were not appropriate for their purposes.

Students were generally found to be very careful in setting up their experimental procedures. However, they varied in the degree to which they systematically collected their data. For example in the decomposition project one group failed to record the same information each time and instead focused on phenomena that attracted their attention and they failed to consider how these phenomena were related to the question that they were investigating. This inconsistency in data collection and failure to link observations to the guiding question likely impacted their ability to learn about the scientific concepts that they were investigating.

During the process of carrying out their investigations, students had sporadic conversations about the scientific meanings of their observations, usually spurred by incidental observations that attracted student attention. However, students often did not pursue the scientific implications of what they noticed or relate them back to their original question. In this study the authors also found that students frequently visited other groups to see what they were doing. During these times they debated the quality of the various investigations. However, they generally used something that was interesting or unique about the procedures rather than the question, in making judgments about which investigations they thought were best.

When students analyzed data and drew conclusions, they often did not summarize their data or discuss patterns. Students often stated their conclusions without discussing the data that led them to that conclusion. For students who did refer to their data, some did not use all of the data that they collected in drawing their conclusions. At times this resulted in ignoring information that might have led to a different conclusion. In addition, some students did not relate their conclusions back to the original question. The degree to which students referred to background information in justifying their conclusions also varied.

During the final presentations, students tended to give brief summaries of what they had done and what they found. The presentations did not provide the opportunity for the groups to compare and synthesize what they had done in order to further their understanding of the underlying scientific concepts that they were investigating.

In summary, the authors found that there were challenges related to choosing a driving question that can allow for small-scale student investigations and still connect to larger scientific issues. Students may need guidance in selecting meaningful questions. The authors suggest that it may be productive to have students explain how their questions relate to an out of school issue and to the driving question. The students in this study were also often not clear about the purpose of the measures that they chose in their investigations and students may need to be encouraged to explain why they chose the procedures and measures that they are using in their investigations. Students also tended to focus on the procedures of their investigations rather than the content of their investigations and students may need more scaffolding to keep their attention focused on the content of the investigation and the questions they are focused on answering.

A study by Scardamalia and Bereiter (1992) specifically examined students' ability to generate questions. The 5th and 6th grade classrooms in this study used Computer-Supported Intentional Learning Environments (CSILE), in which students generated questions and then sought out answers to their questions, which they then posted to the community database. The questions were not directly investigated by the students by collecting original data, but rather were used as springboards for further discussion and information gathering used to answer the questions. Although this study differs from the inquiry nature of other studies in this review, it does provide insight into students' ability to generate questions that may or may not lead to better conceptual understanding of the concepts under investigation. In this study, students' questions were analyzed for their likelihood to advance student knowledge, explanatory nature of the question, the interest level of the question, and the complexity of the search needed to answer the question. In general, students tended to generate low-level factual questions rather than questions that could extend their understanding of a topic. However, when students based their questions on their own prior knowledge, their generation of questions that would produce a "significant addition to knowledge or an advance in conceptual understanding" was significantly higher (46%) than when the questions were based on text that they had recently studied (4%).

When students asked questions prior to studying a topic, their level of prior knowledge about the topic influenced the level of questions that they asked. If students already had a basic understanding of the topic, then the questions they asked tended to have the potential to extend their conceptual understanding. However, if they lacked basic knowledge about the topic, then their questions tended to focus on questions at a more factual level.

These studies show that students do not inherently connect their investigations to the underlying scientific concepts that they are suppose to be investigating. In general, students' small group discussions during inquiry-based teaching focused more on procedural aspects of the tasks rather than on making meaning of their observations or of the questions that they have been asked to address. This is likely to influence student learning of the science concepts that these lessons were meant to address. In addition, the specific nature of the questions that students investigate, the collection and analysis of data, and the drawing of conclusions are also likely to influence the degree to which their investigations lead to deeper understanding of the underlying science concepts. In particular, students appear to need assistance in developing questions for investigation and linking their investigations and conclusions to the original question if science content learning is to be a goal of these inquiry-based lessons.

The Role of Explanations in Scientific Inquiry

A relevant area of research, related to understanding students reasoning about science concepts during inquiry, focuses on students reasoning about explanations. As described previously, inquiry-based instruction has historically been defined in a variety of ways. In some cases, inquiry instruction referred primarily to the learning of science process skills. Recently, the focus on inquiry instruction has shifted from an emphasis on processes and experiments to a focus on explanation and argument. Four of the five essential features of classroom inquiry identified by the NRC (2000) emphasize the importance of explanations.

Some have suggested that teaching about scientific evidence and explanations should be a central part of the science curriculum (Duggan & Gott, 2000; Driver et al., 2000). Duschl (1990) argued for the importance of using scientific theories and reasoning about evidence for theories as a guiding framework for curriculum development. Recent studies on models of inquiry instruction have focused on providing explicit supports for students' development of and reasoning about explanations during inquiry (Kuhn & Reiser, 2005; Sandoval & Reiser, 2004; Osborne, Erduran, and Simon, 2004a; Zembal-Saul, 2005).

What is an explanation? Defining what an explanation is and the types of explanations that exist depends upon the purpose for creating the definition and the context in which the explanation is required. There are distinct differences in how philosophers, scientists, and educators define explanations (Edgington, 1997).

There has been much written in the philosophy of science literature about what exactly constitutes an explanation, a scientific explanation, or a correct explanation (Pitt, 1988). Two models of causal explanation derived from a philosophical perspective include the deductive-nomological (D-N) model of explanation and the statistical-probabilistic (S-P) model of explanations. Hempel and Oppenheim (1988/1948) proposed the D-N model that defines explanations as an argument in which an empirical phenomenon is logically deduced from a set of general laws and statements of antecedent conditions.

The S-P model of explanations expands on the D-N model to include statistical laws as well as general laws. In addition, in this form the nature of the deduction between the explanans and the explanandum is probabilistic rather than deductive (Martin, 1977). Explanations of this form consist of laws that describe probabilities of events occurring. These laws may be stated in forms such as nearly all A's are B, or there's a 90% chance of A being B. Explanations related to evolutionary theory are often of this form. For example, explaining why species have certain characteristics may rely on explaining how, in a certain environment, organisms with those characteristics are more likely to survive than organisms lacking those characteristics.

Others have argued that these models are too limiting. Scriven (1988) provides a number of criticisms of the D-N model including the following (p. 67).

> 1. It fails to make the crucial distinction between explanations, grounds for explanations, predictions, things to be explained, and the description of these things.
> 2. It is too restrictive in that it excludes their own examples and almost every ordinary scientific one.
> 3. It is too inclusive and admits entirely nonexplanatory schema.
> 4. It requires an account of cause, law, and probability which are basically unsound.
> 5. It leaves out of account three notions that are in fact essential for an account of scientific explanation: context, judgment, and understanding.

These philosophical discussions provide an important framework for looking at scientific explanations. However, they are not sufficient for understanding the development and use of explanations among children and adults. Science education takes a much broader view of the nature of explanations in order to encompass the various ways in which explanations may be expressed and used when reasoning about phenomena.

Brewer, Chinn, and Samarapungavan (2000) broadly define explanations as a conceptual framework for a phenomenon that leads to a feeling of understanding in the reader or the hearer. They describe three types of explanations including causal or mechanical, functional, and intentional. Causal or mechanical explanations would include forms such as the D-N and S-P models described above. Functional explanations explain on object or event by its function. For example, birds have wings so that they can fly. Intentional explanations generally refer to explanations involving human behavior, such as explaining that someone turned left at the stoplight because they were going to the grocery store that was in that direction.

In a review of children's explanations, Solomon (1986) described additional types of explanations that children employ. These include pre-causal explanations, theoretical explanations, and metaphorical explanations. Young children often provide explanations that do not imply causal links. These pre-causal explanations include reaffirmation, teleology, tautology and simple juxtaposition. Solomon makes a distinction between causal explanations that identify specific aspects of the system responsible for the event and theoretical explanations that employ scientific concepts to explain the event. For example, a causal explanation of how a washing machine works could include a description of how turning the "on-off" control affects the mechanics inside the washer. A theoretical explanation would include electromagnetic theory applied to the motor.

Solomon also describes the role of metaphorical explanations in scientific inquiry and students' reasoning. Metaphorical explanations include pedagogical and theory-constitutive forms. The pedagogical form is primarily descriptive without providing any deeper insight into the workings of the thing being explained, for example "black holes". Theory-constitutive metaphorical explanations impose a mechanism that suggests causes and effects.

Student Discourse Related to Argumentation

A related line of research that examines the nature of student discourse and provides insight into student learning of science during inquiry has focused specifically on student argumentation. These studies examine students' development of claims or explanations and their use of evidence to support their claims. In these studies the use of the term "claim" refers to conclusions and explanations that students develop as a result of their investigations. This differs from the use of the term "claim" in the Claims-Evidence Inquiry model where the claim refers to a scientific claim provided to students at the beginning of the inquiry.

The process of relating evidence to theory is often difficult for students (Driver et al., 1996; Kuhn et al., 1988). In addition, studies of inquiry-based lessons have found that students make few claims as they engage in inquiry investigations and often use inadequate evidence to support their claims (Watson et al., 2004; Sandoval, 2003; Jimenez-Aleixandre et al., 2000).

Watson et al. (2004) examined student discourse during scientific inquiry lessons in two 8th grade classrooms. They found that students made few claims related to the classroom investigations they were conducting and rarely supported their claims with evidence. Watson et al. suggests that several classroom practices influenced student understanding of the relationship between evidence and explanation. The inquiry investigations followed a common routine in which students mainly focused on getting results and accomplishing the task. Students tended to see their data and results as the same thing and felt no need to explain their results. The teachers reinforced this by acknowledging student claims without asking them to justify these claims.

Several studies have been conducted examining the use of domain-specific scaffolding of student explanations within the context of the Biology Guided Inquiry Learning Environment (BGuILE) (Tabak et al., 1998). BGuILE is a computer based learning environment that includes a set of supports to help students organize and manage the complexity of the data available, design systematic and informative comparisons, and domain-specific strategic supports which guide students towards important domain-specific concepts.

Studies of student-generated explanations in Biology Guided Inquiry Learning Environments (BGuILE) examined students' use of data to generate explanations and support claims. In this learning environment Sandoval (2003) found that students used data to generate explanations, but often failed to cite data to support their claims. The BGuILE learning environment was successful at encouraging an orientation to data as something to be explained. However, students rarely explicitly cited the data when making claims. The author suggests that this was constrained both by their ability to make sense of the data and by their epistemic ideas about what evidence is necessary to support a claim.

In a follow-up study, Sandoval and Millwood (2005) examined the quality of students' use of evidence in written explanations generated during lessons using the BGuILE computer simulations. The analysis framework in this study examined the conceptual quality, the sufficiency of evidence and the rhetorical reference made to inscriptions in students explanations. Prior studies of student argumentation based on Toulmin's (1958) argument structure examined how students provide warrants for claims, how they do so and on what basis, but they did not examine whether or not those warrants are appropriate or sufficient for the claim (Park & Flick, 2004). The framework in the Sandoval and Millwood study allowed for examination of the conceptual quality of the claims and the evidence being used to support them.

Examination of student explanations in this study found that the students cited data for the majority of their claims, however, they often failed to cite sufficient data and they often failed to identify how specific data related to their claims. Some of these results are likely due to students' epistemological ideas about explanations. For example, students may have seen citing data as sufficient for supporting their explanations and not perceived a need to cite multiple examples of data or explain how the data relates to the claim. However, some of the results may also indicate limits to students' understanding of important concepts. For example, when citing data for a differential trait some students only cited data for one group rather than recognizing that a comparison of the two groups was necessary. This failure to cite sufficient data may reflect a lack of understanding of the meaning of the concept of a differential trait.

Understanding the Forms of Causality Implicit in Students' Explanations

Research on student explanations suggests that the forms of causality that students use to explain scientific phenomena can influence their understanding of scientifically accepted explanations. Grotzer (2003) suggests, "…students' and scientists' explanations often have a different underlying causal structure and that students' relatively limited causal repertoire is an important and systematic source of alternative conceptions in science" (p. 3). She suggests, "Developing sophisticated causal understanding is critical to developing deep scientific understanding." (Grotzer, 2003, p. 4)

Grotzer and Perkins (2000) developed the Taxonomy of Causal Models to characterize levels of reasoning about the nature of causality in scientific explanations (Table 1). This model consists of four dimensions: Mechanism, Interaction Pattern, Probability, and Agency. Levels of increasing complexity are identified and described within each dimension. This taxonomy provides a framework for examining the nature of causality in students' explanations.

Table 1. Dimensions of causal complexity in models (reprinted from Grotzer, 2003)

Mechanism From a same-level generalization to an inferred underlying mechanism.	**Interaction Pattern** From A causes B to complex reciprocal relations and constraint systems.
Surface generalization: Simply describes the regularity under consideration in a generalized way *("When it is hot and it rains, there is lightning")*. Often incorrect or confuses correlation with causation. *("Heat and rain cause lightning.")* ***Token agent:*** Some entity or phenomenon, intentional or not, made things come out that way. Entity/phenomenon's behavior parallels outcome, no real differentiation *("Static electricity makes it happen")*. ***Functional explanation:*** Explains in terms of purpose (*Why is some current AC? So we can move electricity long distance without overheating wires.*) Might be teleological, effect is given as cause (*Giraffes have long necks so that they can eat the leaves on top of the trees*) ***Commonplace elements:*** Constructs explanations with familiar elements of the system in question rather than those underlying it. (*Can be illuminating. Darwin's theory of natural selection explains not at the genetic level but in terms of observable adaptive traits, the everyday notion of inheritance, etc.*) ***Analogical model:*** System explains target phenomena by analogy and analogical mapping (e.g. electricity as fluid flow). ***Underlying mechanism:*** Properties, entities, and rules introduced that are not part of the surface situation but account for it (e.g. Ohm's law; and underneath that electrons and their rules of conduct. *Note: There are often two or three levels of underlying mechanism, each underlying the previous).*	***Simple linear causality***: A impinges on, pushes, influences B. A is seen as not affected. (e.g. A pushes, pulls, initiates, resists, supports, stops B. A is typically seen as active as in pushing, but can be passive as in resisting). ***Multiple linear causality:*** Multiple unidirectional causes and/or effects; multiple immediate causes and/or multiple immediate effects; Domino causalities where effects in turn become causes as in simple causal chains like A causes B causes C or branching patterns; Necessary and sufficient causes, etc. Often includes previously neglected agents of lower saliency in the causal story. ***Mediating cause:*** At least three agents in play, M mediates the effect of A on B but not simply in the sense of A causes M causes B (e.g. M is a barrier to A affecting B, or a catalyst, or an enabling condition). ***Interactive causality:*** Two-Way Causality; Interactive causation with a mutual effect (*as in particle attraction*); Mutual cause with two outcomes (*as in symbiosis*); Relational causality where the outcome is due to the relationship between two variables (*as in pressure or density differentials*). ***Re-entrant causality:*** Simple causal loops as in escalation and homeostasis. ***Constraint-based causality:*** Behavior of system reflects a set of constraints that the system "obeys" – constancy, conservation, and covariation rules (e.g. conservation of energy, Ohm's law, law of gravitation).

Table 1 (continued). Dimensions of causal complexity in models (reprinted from Grotzer, 2003)

Probability From deterministic causality to chaotic and quantum systems.	**Agency** From a central and direct agent to highly emergent causality.
Deterministic systems: Certain consequences, inevitable, and predictable outcomes (*e.g. as in Ohm's law, law of gravitation)*. ***Noisy systems:*** Basically deterministic systems perturbed by random or unanalyzed factors (*air friction, turbulence on thrown objects)* ***Chancy systems:*** At certain junctures, things might go one way or another with a certain probability. ***Chaotic Systems:*** Fundamental unpredictability in long term due to "butterfly effects" (*e.g. the weather*). ***Order from chaos:*** Averaging effects smooth out chaotic systems into highly orderly large-scale patterns (*e.g. gas laws*). ***Fundamentally uncertain systems:*** As in quantum theory, uncertainty built into the nature of objects and events, even for very small systems in the very short term.	***Central agents with immediate influence:*** One or a very small number of key factors fairly directly yield the result. May be interwoven with intentional causality. ***Long causal chains, branching structures, cycles:*** *(e.g. as in ripple effects of an ecological disaster.)* ***Aggregate effects:*** Cumulative effects over time (*e.g. erosion).* ***Causal webs:*** Complex web of interactions, often involving reasoning at the population level (*as in ecologies).* ***Trigger effects:*** A modest influence "topples" a complex system into a new state or pattern of activity. *("Tipping points").* ***Self-organizing systems:*** Seemingly messy systems evolve into clear patterns over time without an external agent or an internal blueprint. ***Emergent entities and processes:*** Agency is distributed. The actions of many individual agents at a lower level converge to give rise to new complex patterns that are not easily anticipated based on the lower order actions. *(as with the emergence of new species, chemical compounds, etc.)*

The *Mechanism* dimension describes the processes by which an effect comes about. Lower levels of causality complexity in this dimension invoke mechanisms that can be directly perceived. Higher levels in this dimension invoke mechanisms involving more abstract entities, such as momentum or electrons. Developmental research shows that by about age three many children appreciate the need for causal mechanisms even if they cannot fully explain them (Gelman and Gottfried, 1996). Between the ages of three and five children begin to acknowledge non-perceivable causes, such as invisible contaminants (Au, Sidle, and Rollins, 1993). However, the science education research suggests that students continue to have difficulties reasoning about indirect mechanisms into adolescence. For example, many students appear unaware of the role that microscopic organisms play in decomposition (Leach, Driver, Scott, & Wood-Robinson, 1992).

The *Interaction Pattern* dimension describes the nature of interactions between causes and effects. The simplest levels in this dimension involve linear reasoning about the relationship between two variables, i.e. A causes B. Higher levels invoke multiple unidirectional causes and/or effects (multiple linear causality), additional causes which may act as a barrier or catalyst (mediating causality), two-way causality (interactive causality), simple causal loops (re-entrant causality), and causality that is constrained by a system of rules (constraint-based causality). Developmental research suggests that children around the ages of three to five begin to gain the ability to detect indirect effects in simple physical contexts (Shultz, Pardo, and Altmann, 1982). However, science education research suggests that students often fail to reason about indirect effects in more abstract contexts such as food webs (Griffiths & Grant, 1985). Research related to mediating causes suggests that children as young as 3 can reason about mediating causes, but that facilitating causes are easier for young children to understand than inhibitory causes (Sedlak and Kurtz, 1981).

The *Probability* dimension refers to the level of certainty invoked in identifying relationships between causes and effects. At the lower levels in this dimension the relationship between cause and effect is 100%. At higher levels probability comes into play. Noisy systems may be perturbed by random events. Chancy systems may have unpredicted results under certain circumstances. Chaotic systems are fundamentally unpredictable due to the complexity of the system. In “order from chaos”, averaging effects smooth out chaotic systems. In fundamentally uncertain systems, the nature of the very elements that are being reasoned about are uncertain, as in quantum theory. Developmental research suggests that children can grasp some aspects of uncertainty by age five. However, understanding and applying the concept appears to develop later. Metz (1998) found that kindergartners were able to recognize uncertainty in some cases, third graders grasped the concept of randomness, but rarely used it, and adults revealed integrated concept of uncertainty and probability.

The *Agency* dimension involves the identification of the cause that is being reasoned about. At lower levels in this dimension the result is due to one or very few direct causes. At higher levels, causes consist of chains of causes, cumulative effects, trigger effects, self-organizing systems, or emergent entities and processes. Developmental research suggests that the ability to detect causes that are spatially or temporally remote develops with age. Infants do not recognize causal agents that occur spatially or temporally removed from the effect (Michotte 1963). Elementary school students were found to begin to deal with time delays if the cause consistently covaried with the response (Siegler, 1975).

Grotzer (2003) suggests that scientists are more likely to reason at higher levels of complexity within the taxonomy, but that explanations may be constructed at various levels depending upon the particular purpose. For example, “…a scientist might talk in shorthand about the pull of Earth’s gravity on objects as a simple linear pattern without talking about it as an equal and opposite attraction between two bodies that have mass as in interactive causality.” (p. 5)

Examination of students’ explanations and the evidence they use to support them can provide insight into the nature of the knowledge that they are constructing as they engage in inquiry-based instruction. However, the construction of evidence-based explanations is a skill in itself and the studies above suggest that it is influenced by students’ reasoning skills, epistemological understanding of the nature of explanations and by their knowledge of the domain. If students are to construct meaning from inquiry-based investigations we must specifically examine the nature of their ability to connect evidence to explanations and the factors that influence this ability.

Claims-Evidence

Description of the Claims-Evidence Inquiry Model

Claims-Evidence is an inquiry-based instructional strategy that uses a deductive approach to question generation, in which scientific claims are used as springboards for student investigations (Gummer, 2002; Thompson, 2003; Briley, 2003). The claims may be scientific theories, laws, or hypotheses. Instead of providing students with a question for investigation or having students generate their own questions based on a specific topic or a topic of their choosing, the Claims-Evidence model focuses student questions and investigations on scientific claims. The claims can be provided by the teacher or identified by the student and often come from statements taken straight out of science textbooks or standards documents.

In the Claims-Evidence model students are encouraged to consider how their questions, procedures, and conclusions relate to the claim they are testing. This encourages students to link their evidence and explanations to the underlying science concepts rather than merely stating whether their data supports their hypothesis or not. By having all student investigations focused on one claim, students can see how multiple lines of evidence are used to test scientific claims. A key component of the Claims-Evidence model involves students examining each other's investigations to see how results of the different investigations relate to the claim. This allows students to examine and discuss the quality of the evidence from the different investigations and the relationship between the evidence and the scientific concepts of the original claim.

The idea of examining the validity of claims as an instructional approach is not entirely new. Joseph Schwab (1962) suggested that one form of classroom inquiry could begin by giving students propositions and having them devise means of testing them. In an example of an investigation of floating and sinking, Schwab describes how the teacher would begin by having the students read two propositions from a study of Archimedes' On Floating Bodies and then "devise a laboratory procedure for testing the soundness of either of the two Propositions" (p. 57). Schwab also suggested that students could be asked to examine their textbook, teachers' lectures, and scientific papers in order to evaluate the validity of claims made by others and the adequacy of the evidence they presented.

Current Use of the Claims-Evidence Model in Oregon

The Claims-Evidence model as it is currently being used in Oregon was initially developed by the Oregon Science Leaders and has been the main focus of the Oregon Science Teacher Leader Institutes for the last 3 years (Gummer, 2002; Thompson, 2003; Briley, 2003). This model is now being used by a number of teachers throughout the state of Oregon. Anecdotal accounts from teachers suggest that the Claims-Evidence model is an effective approach for teaching content through inquiry (Briley, 2003; Thompson, 2003). Teachers describe how students are better able to keep track of the major purpose of the investigation and their decisions about data collection, display, and interpretation are more closely tied to the original claim. They also feel that this approach results in better arguments related to student investigations and more critical thinking when interpreting results. In addition, the teachers describe how this model focuses student investigations on significant ideas in science and allows students to learn important content while doing inquiry. However, little research has been conducted to examine its use in the classroom or its effectiveness at improving student understanding of disciplinary science content.

Summary

Inquiry-based instruction has a long history in science education and recent reform documents have encouraged its use as an important means of teaching students science content, understandings about science, and skills of conducting scientific investigations. The focus on inquiry-based instruction is supported by theories of learning that emphasize the importance of active engagement with phenomena (Piaget & Inhelder, 1969; Bruner, 1960; Bransford et al., 2000) and social interactions to support construction of knowledge (Schunk, 2000).

Examination of the specific nature of student and teacher behaviors during inquiry has begun to provide insight into the multitude of factors that may be influencing student learning during inquiry-based instruction. The ways in which teachers structure inquiry activities and engage in discourse with students is also likely to have an impact on the degree to which students develop understandings of the underlying science concepts that they are investigating. Studies of teacher behavior during inquiry have found that the emphasis that teachers place on student understanding of domain concepts and the strategies that they use during inquiry can vary widely between teachers and between activities. Inquiry-based teaching is multidimensional and requires negotiating a number of trade-offs. Understanding the various ways in which teachers implement inquiry-based curricula and instructional models is important to understanding the ultimate influence that inquiry instruction can have on developing students understanding of science concepts.

Inquiry-based teaching provides challenges for students in terms of the need to navigate through all of the procedural aspects of the task and still maintain a focus on the conceptual questions to which the investigations are connected. The studies reviewed above suggest that without supportive teacher guidance students will tend to place priority on the procedural aspects of the task and do not necessarily connect their investigations to the underlying scientific concepts that teachers hope they are learning. Specifically, the types of questions that students generate may tend to focus more on personal interest and address aspects of low-level factual interest rather than questions that would lead to deeper understanding of the science concepts that are the focus of the investigations. Even when the questions themselves could lead to relevant investigations, students often failed to connect their investigations and conclusions to those questions.

Examination of student discourse about explanations provides further insight into student reasoning about science concepts during inquiry. During inquiry, explanations provide causal accounts of how or why something happened or will happen. Studies that specifically examined student discourse and argumentation found that in situations in which teachers and/or the curriculum did not provide specific guidance for the formation of claims or explanations (Watson et al., 2004), students made few claims related to their investigations and rarely supported those claims with evidence. When using curriculum that specifically supported the development of explanations, such as the BGuILE curriculum, students cited evidence for the majority of their claims, but that evidence was of varying quality and students rarely explained how the evidence related to their data. Understanding how evidence is used to develop explanations and evaluate claims is an important aspect of understanding the nature of scientific inquiry and an important component in the meaning that students make from the data that they collect during inquiry investigations.

Understanding the reasoning that students are engaging in related to science concepts during inquiry examining the forms of causality implicit in student explanations. Explanations can be constructed at various levels of causal complexity and limitations in students' causal reasoning may influence the knowledge they construct from inquiry experiences. Grotzer (2003) provides a useful framework for examining the various dimensions and levels of complexity in causal explanations.

In order to better understand the relationship between inquiry instruction and student learning of science concepts, an in-depth study is needed which specifically examines the nature of student and teacher discourse during specific types of inquiry instruction and the relationship to student learning of science content. Inquiry teaching models may vary in the amount of emphasis that is placed on learning science content versus learning processes of inquiry. Therefore, this study is focused on a specific instructional model (Claims-Evidence) that places student learning of disciplinary science content as an important outcome of the inquiry instruction.

Furthermore, students' construction of knowledge is related to and influenced by the context within which it is developed. Understanding the influence of particular inquiry teaching models on student learning can be greatly enhanced by examining student cognition from a situated perspective that examines student learning within the context of the instruction, rather than merely as an outcome of the instruction. Combining measures of student achievement before and after instruction along with an in-depth analysis of student engagement during inquiry can begin to identify specific aspects of inquiry instruction which may be related to students' development of an understanding of the scientific concepts underlying their inquiry investigations.

CHAPTER III
DESIGN AND METHOD

Research Questions

1. What aspects of instruction influence student's engagement with the science concepts and their ability to link claims to evidence?
2. Where in the inquiry cycle do students invoke explanations and what is the nature of those explanations?
3. What is the nature of student reasoning when explaining the relationship between the results and the claim?
    a. In the analysis section of the inquiry reports, do students connect their results to the claim that they are investigating?
    b. What is the nature of the connections that students make between the results and the claim? (i.e. in regards to the concept of conservation of momentum, forms of causality, and relationships between the independent variable, dependent variable, and momentum)
4. What changes occur in student understanding of science concepts as a result of engagement in Claims-Evidence inquiry lessons?

Methodology

Theoretical Framework

An interpretivist epistemological perspective (Schwandt, 2003) undergirds this research. This perspective acknowledges that there are patterns in human behavior that can be observed, but that the recognition and interpretation of these patterns is influenced by the theoretical perspective and interpretive framework of the observer. The theoretical perspective taken in this research is one that sees learning of science as knowledge construction involving both individual and social processes (Driver et al. 1994). This perspective suggests that it is both students' personal meaning-making through individual experiences and their engagement in classroom discourse with teachers and peers that leads to construction of students' scientific knowledge.

Methodological Framework

This study uses a situative methodological perspective (Borko, 2004) that allows for multiple conceptual perspectives and multiple units of analysis. A conceptual framework based on causal reasoning (Grotzer & Perkins, 2000) is used to examine individual student cognition and learning of science content. A socio-cultural conceptual framework (Lemke, 2001) is used to examine the social context of the classroom as well as patterns of student and teacher participation in learning activities.

A multiple-case sampling methodology (Miles and Huberman, 1994) was used to examine student learning in classrooms using Claims-Evidence Inquiry. The multiple levels of analysis examined in this study resulted in a case within case study design (Figure 1). The primary case of interest is the Water Rocket Inquiry. Within this case, the individual instruction of two teachers (T_a and T_b) using the same Claims-Evidence task was examined. There was substantial overlap between these two teachers in terms of the nature of their instruction. Therefore, the results are reported primarily in terms of the Water Rocket Inquiry in general. Differences between the instructions of the two teachers are noted where relevant. Within one class of each teacher, two focus groups of students (G_m and G_f) were chosen and followed throughout the entire inquiry.

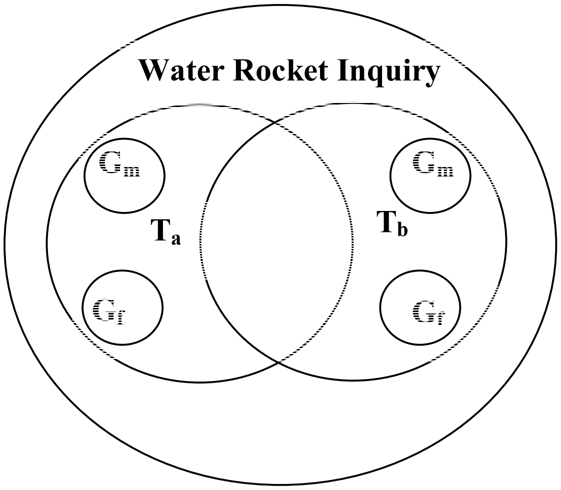

Figure 1. Study design: cases within cases

School Context

This study was conducted at a suburban middle school in northwestern Oregon. The school currently has an enrollment of 1065 seventh and eighth graders. The ethnic composition of the school is 80% white, 1% black, 4% Hispanic, 10% Asian/Pacific Islander, 1% American Indian/Alaskan Native, and 5% Multi-racial/Multi-ethnic. 20.5% of the students at the school qualify for free and reduced lunch. The percentage of minority students and students eligible for free and reduced lunches are slightly below the state averages of 27.7% minority students and 41.9% free and reduced lunch.

Subjects

The teachers in this study were purposefully selected (Patton, 2002) because of their experience using Claims-Evidence Inquiry in their classrooms. To examine the use of the Claims-Evidence model and its influence on student learning of science content it is important to begin by examining classrooms in which this approach has been used in previous years. This avoids possible confounding influences of teacher inexperience. Implementation of any instructional model is influenced by socio-cultural characteristics specific to the teacher and the student make-up of the class, therefore comparison across classes by the same teacher and by different teachers allows for examination of how the model is used in different classroom contexts. Both teachers currently teach 8th grade at the same school and have been using the same inquiry activities based on the Claims-Evidence approach for the last three years.

Anne has been a facilitator at the Oregon Science Teacher Leader Institutes (OSTLI) for the past two years training other teachers how to use the Claims-Evidence Approach and attended OSTLI as a participant for one year before that. She has also developed three inquiry activities based on the Claims-Evidence Approach that she has used in her classroom for the past three years. Anne has been teaching middle school science for 10 years.

Brenda has attended three OSTLI workshops as a participant and has been using Claims-Evidence inquiry activities in her classroom for three years. She has been teaching middle school science for three years.

In addition to the teachers, the subjects of this study also include the students in each of the teachers' classes. The teachers each teach five classes in which they use these activities. However, one of Brenda's classes contains a large number of English Language Learners (ELL) students and another was taught by a student teacher during the study, so they were not included in the analysis.

The students in all classes took pre- and post-content assessments developed for this study (see p. 46) and completed Scientific Inquiry Final Reports. Only the data from students who returned student and parent permission forms and gave consent to participate in the study were used for the analysis. The percentage of students who consented to participate in the study ranged from 48%-97% (Table 2). The return rates tended to be lower among Anne's classes than Brenda's classes.

Table 2. Student consent by class

Teacher	Class	Total # of Students	# of Students Who Gave Consent (%)
Anne	1	30	15 (50%)
	2	32	22 (69%)
	3	35	29 (83%)
	4	31	15 (48%)
	5	32	24 (75%)
Brenda	4	33	32 (97%)
	5	34	28 (82%)
	6	32	29 (91%)
Total		259	194 (75%)

Table 3 contains a breakdown of the student composition of the 8 classes in this study. Anne's classes tended to consist of more Talented and Gifted (TAG) and students on Individualized Education Plans (IEP), whereas Brenda's classes tended to consist of more ELL students.

Table 3. Student composition in the study classes (Numbers in parentheses are the number of students in each group that consented to be in the study)

Teacher	**Class**	**Total Number of Students**	**# TAG Students**	**# of IEP Students**	**# of ELL Students**
Anne	1	30	2 (2)	2 (0)	
	2	32	9 (8)	3 (1)	
	3	35	15 (14)	2 (2)	
	4	31		6 (3)	
	5	32		4 (3)	
Brenda	4	33			3 (3)
	5	34			5 (3)
	6	32		2 (1)	1 (0)
Total		259	26 (24)	19 (10)	9 (6)

Examination of the number of students that returned consent forms in each of these groups shows that a lower percentage of the IEP and ELL students returned permission forms than TAG or non-identified students (Table 4). This variation in return rates may result in a slightly greater representation of higher ability students than lower ability students in the data used for this study.

Table 4. Student consent by student group

Student Group	**Total # of Students**	**Consent**	
		Number	**Percent**
Non-identified	195	154	79%
TAG	26	24	92%
ELL	9	6	67%
IEP	19	10	53%

One class taught by each of the teachers was chosen to conduct an in-depth qualitative analysis of student learning and instruction during the inquiry activities. The classes were selected based on convenience, the percentage of students who gave consent to be involved in the research, and the teachers recommendations of which classes did not have issues that may confound the analysis (i.e. major behavior problems). Anne's 3rd period class and teacher Brenda's 4th period class were selected for this part of the study. The target classes were observed and videotaped everyday during the water rocket inquiry.

In addition, two small groups composed of four students each from each target class were selected and audiotaped to capture student discourse during the inquiry investigations. During this inquiry the teachers chose to group the students homogenously by sex and ability. The teachers made this decision based on experiences from previous years when some students tended to dominate aspects of the inquiry, such as building the rockets, in heterogeneously mixed groups. Due to the nature of the student grouping a decision was made to choose one student group composed of average ability boys and one group composed of average ability girls in each class. The determination of average ability was made based on the teachers' knowledge of the students and students' TAG or IEP status. Three of the groups consisted of four students not identified as TAG or IEP. However, in Anne's class all of the groups composed of female students included at least one TAG student. In this case a group was chosen which consisted of one TAG student and one student on an IEP. The groups were also selected based on their willingness to participate and be videotaped and their parents' permission to partake in the study. The following codes will be used to identify the four groups (Table 5)

Table 5. Group codes

Codes for Focus Groups	**Description**	**Student Breakdown**
T_aG_f	Anne's class, Group of female students	One TAG student (S_1) and one IEP student (S_2)
T_aG_m	Anne's class, Group of male students	No students identified TAG or IEP
T_bG_f	Brenda's class, Group of female students	No students identified TAG or IEP
T_bG_m	Brenda's class, Group of male students	No students identified TAG or IEP

Data Collection

Data collection consisted of four main components including classroom observations, student inquiry reports, teacher interviews, and pre- and post-assessments focused on content knowledge related to the inquiry investigation. Data collected during the classroom observations included field notes, audiotaped recordings of student and teacher discourse, teacher handouts, and student products (Table 6).

Table 6. Relationship between research questions, data sources, and analysis methods

Research Questions	**Data Sources**	**Analysis Methods**
1. What aspects of instruction influence student's engagement with the science concepts and their ability to link claims to evidence?	• Teacher Interviews • Classroom observations, field notes • Instructional artifacts	Cycles of inductive and deductive analysis using analytic framework based on explanations.
2. When in the inquiry cycle do students invoke explanations and what is the nature of those explanations?	• Student discourse from the 4 target groups. • Inquiry Reports from the 4 target groups.	Inductive analysis.
3. Do students make a substantive link between evidence and the claim? a. In the analysis section of the inquiry reports, do students connect their results to the claim that they are investigating? b. What is the nature of the connections that students make between the results and the claim? (i.e. in regards to the concept of conservation of momentum, forms of causality, and relationships between the independent variable, dependent variable, and momentum)	• Analysis sections of Inquiry Reports from students in all 8 classes.	Analysis based on causal representations of student explanations compared to canonical explanations.
4. What changes occur in student understanding of science concepts as a result of engagement in Claims-Evidence inquiry lessons?	• Student Pre- and post assessments of disciplinary knowledge	One-way ANOVA to identify class effects among the 8 classes. Paired t-tests to identify differences between pre-test and post-test scores.

Classroom Observations

Classroom observations were conducted in the target classes during all classroom sessions of the Water Rocket Inquiry. During these sessions the classes were observed, videotaped, and the two focus groups of students in each class were audiotaped. The researcher also took field notes during the classroom observations. Prior to the inquiry activities, the researcher visited the classroom twice to observe and to help make students comfortable with her presence. The videotape was used primarily to capture the teachers' instruction and the whole class dynamics. Anne was observed for a total of 11 days and Brenda was observed for a total of 14 days (Table 7). Brenda was absent on one of the days and a substitute teacher taught the classes on that day. This occurred on one of the last days of the inquiry when students were primarily working in their groups to finish writing up their reports. Normal data collection occurred, including audiotaping of the small groups, on this day. During the classroom observations the researcher acted as a non-participant observer.

Table 7. Dates of classroom observations

Teacher	Dates of Observations	Total Number of Days Observed
Anne	10/20/05 – 11/7/05	11
Brenda	10/26/05 – 11/14/05	14*

*Substitute teacher present on one of these days.

Within each target class two small groups of students (total of 4 small groups) were audiotaped during the entire inquiry. Student discourse in these four groups was recorded using a digital audio recorder that was placed in the center of the students' table. The recorder was started at the very beginning of class as students were sitting down and turned off at the very end of class.

It is possible that the presence of the recorder may have affected the nature of student discourse during this study. However, examination of the recordings suggests that students were largely unaffected by the presence of the recorder. On a few occasions students commented about the presence of the recorder when engaged in social discourse in which they made statements they might not want a teacher to hear, but in general they seemed to ignore the presence of the recorder. Students were audiotaped during the entire inquiry except for the actual rocket launches. During the launches the students were outside and moving around for most of the time setting up their rockets, launching them, and collecting them, therefore it was not possible to audiotape the individual groups during this time.

All of the teacher and student discourse related to the inquiry were transcribed from the audio-recordings. Logistical, off-task, and non-inquiry related discussions were not transcribed. The videotapes were used primarily to clarify what occurred in the classroom when the audiotape was unclear.

Teacher handouts and copies of classroom notes were also collected and used as additional evidence of classroom instruction.

Inquiry Reports

At the end of the Water Rocket Student Inquiry, students submitted typed reports of their inquiry investigations. The reports were organized according to the four sections of the Oregon Inquiry Scoring Guide. These final inquiry reports were collected from the students in all eight classes. Digital photographs were taken of all student inquiry reports and select sections were transcribed for further analysis (see data analysis below).

Teacher Interviews

Semi-structured interviews were conducted with each teacher prior to and following the water rocket unit. The pre-inquiry interview addressed the teachers' beliefs about inquiry teaching, the teachers experience with the activity and the Claims-Evidence Approach, their understanding of the relationship between Claims-Evidence and student understanding of science concepts and inquiry, and the teachers' instructional goals for the unit and the activity (See Appendix B). The post-inquiry interview probed the teacher to reflect on how they thought the water rocket inquiry went in terms of their instructional goals and students' ability to link the claim to their results, what components of the inquiry students engaged in reasoning about the science concepts, and any changes they would make to the inquiry in the future (See Appendix C).

The teachers were also interviewed together about the nature of the instruction that the students experienced prior to starting the water rocket inquiry. Prior to the interview, the teachers' lesson plans, handouts, and student journals were examined to develop a chronological description of the instruction that occurred prior to the water rocket inquiry. General descriptions of each activity were written and questions about the nature of the instruction noted. During the interview the teachers were asked to describe the nature of the content (i.e. Newton's first law, second law) and the inquiry (i.e. asking questions, making predictions, supporting predictions, observing phenomena, collecting data, measurement, graphing, identifying patterns, formulating explanations, examining alternative explanations) present in each activity (See Appendices D and E). Both teachers were present during this interview and were asked to note any cases in which instruction varied between their classes.

Pre- and Post-Assessment of Content Knowledge

Students' disciplinary content knowledge related to the Water Rocket inquiry activity was assessed before and after the inquiry activity using a researcher-developed assessment instrument (Appendix F). The assessment consisted of five questions from the Force Concept Inventory (Hestenes et al., 1992) and 3 open-ended questions written by the researcher (Table 8). The Force Concept Inventory examines Newtonian concepts of force, including the first law, second law, third law, and gravity. The original inventory consists of 29 questions and was developed for high school and undergraduate students. An initial examination of the inventory by science educators suggested that the majority of questions are suitable for a middle school level. However, the length of the test is not feasible for use with middle school students in this context. In addition, some of the concepts included in the inventory are not relevant to the Water Rocket activity.

Table 8. Bottle rocket assessment, question type and concept focus

Question	Type of Question	Concept focus of the Question
1	Multiple Choice	Gravitation (acceleration independent of weight)
2	Multiple Choice	Third Law for impulsive forces
3	Multiple Choice	Gravitation & kinds of forces (passive solid contact)
4	Multiple Choice	Third Law for impulsive forces
5	Multiple Choice	Gravitation and air resistance
6	Open-ended	Application of concepts (i.e. third law) to water rocket investigation.
7A/B	Open-ended	Application of concepts (i.e. third law, conservation of momentum) to water rocket investigation.
8A/B	Open-ended	Application of concepts (i.e. second law, conservation of momentum) to water rocket investigation.

In order to focus the questions on concepts that are the most relevant to the activity and to create a test that was of a suitable length the instrument was modified by selecting specific items from the original. Based on the teachers' initial description of the activity and the science concepts that it covers, three science educators with strong backgrounds in physics (Masters or PhD degrees) were asked to review the instrument, identify the questions that they felt were relevant to the Water Rocket Inquiry, and provide an explanation for what concepts they felt these questions covered. The teachers involved in this study were also asked to review the instrument and identify the questions they felt were appropriate for use with the Water Rocket Inquiry. This information was compared and used to select five questions for use in the assessment. A space for students to explain their answers to each of the multiple-choice questions was also included following each multiple-choice question.

In order to assess students' ability to apply their understanding of Newtonian concepts to a context more directly related to the Water Rocket Inquiry a set of open-ended questions (#6-8) were also developed to assess the application of Newtonian concepts to the launch and flight of a rocket. A rubric was developed with acceptable answers to these questions (Appendix G). The Water Rocket Assessment was piloted with another class of middle-school students and some questions were revised before its use in this study.

The pre-test was administered to students following a three-week unit on force and motion. Before being given the pre-test the students were taken outside to observe the launching of two water rockets, one with water in it and one without. The post-test was administered the day after students' inquiry reports were handed in. The same test was used for both the pre-assessment and post-assessment.

Data Analysis

Analytic Framework

The data analysis for this study consists of four parts based on the four research questions. The analytic framework used to examine the data for questions 1-3 evolved as data analysis began. Figure 2 outlines the evolution of the analytic framework and the steps in the data analysis that were conducted. The sequence of analysis steps was not predetermined but rather emerged inductively through interaction with the data (Miles & Huberman, 1994). Prior to the start of the study, an initial analytic framework was developed based on prior studies of teacher and student behavior during inquiry. This analytic framework focused on the relationship between inquiry and learning of science content using an instructional lens that looked at student and teacher behaviors. This resulted in a set of initial macro codes that characterized the instruction into different stages of inquiry as well as micro codes based on student behaviors such as "thoughtfulness with respect to content" and "self regulation" (Krajcik et al., 1998) and teacher behaviors such as "probing for clarification" (Tzou, et al., 2002).

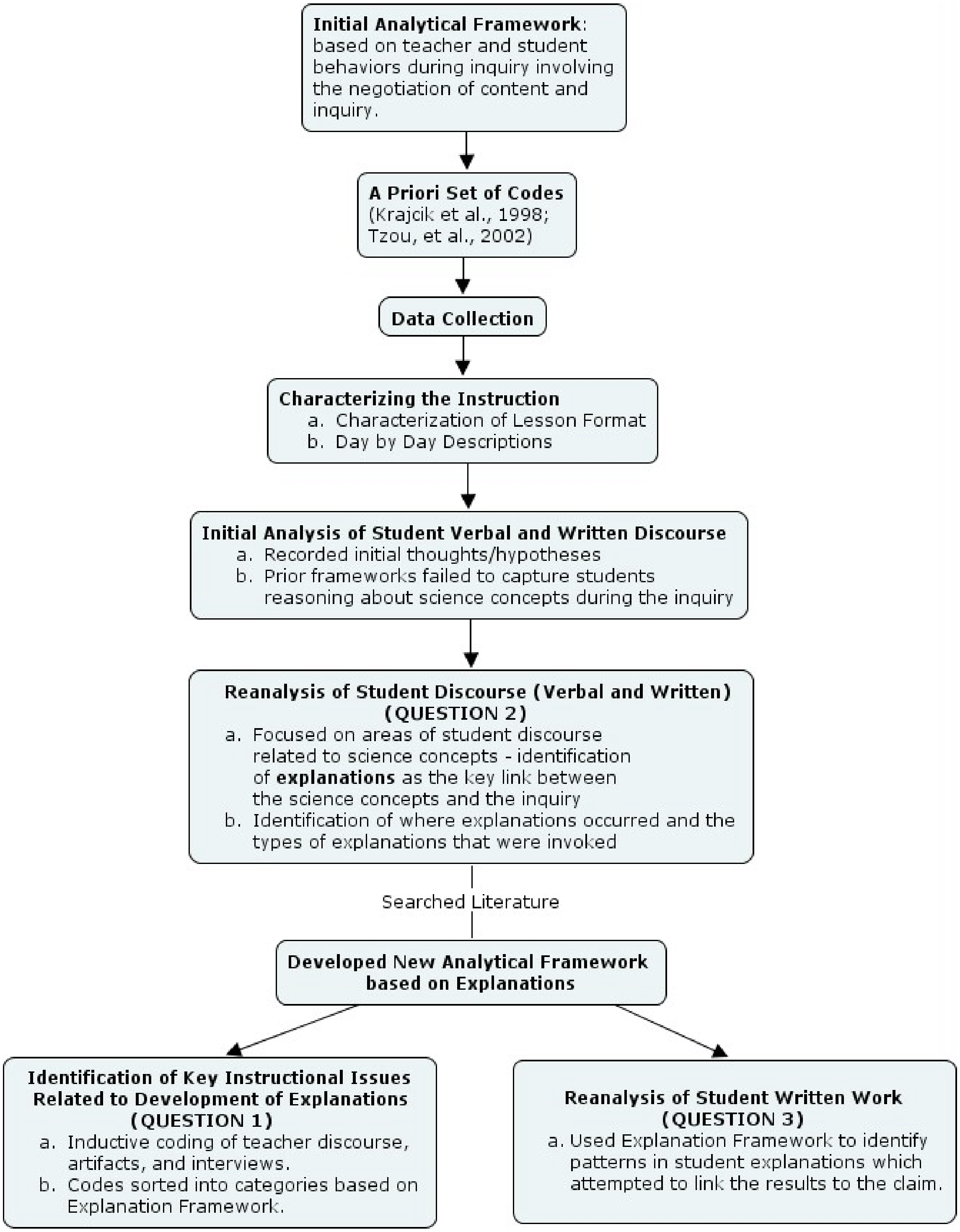

Figure 2. Evolution of Analytic Framework

Following data collection, the initial frameworks were used to create day-by-day descriptions of the instruction that occurred in both teachers' classrooms. The day-by-day descriptions were coded by the focus of the instruction (inquiry, content, and logistics/off-task) and the instructional format (teacher lecture, whole class, small group).

The day-by-day descriptions were then used to identify segments of small group discourse related to science content. These segments were transcribed and initial patterns and hypotheses were recorded during transcription. The analysis sections of the focus students' inquiry reports were also transcribed. The initial analysis of this data focused on question three and consisted of attempts to characterize the nature of the reasoning that students were engaging in about the science concepts connected to their inquiry investigations. The initial macrocodes identified from previous studies of student behavior (Krajcik et al., 1998) allowed for the identification of what students were doing during inquiry and whether it involved reasoning about processes or concepts, but it did not allow for a deeper examination of how students were reasoning about science concepts during inquiry.

After initial attempts to characterize the students reasoning about the science concepts using previous frameworks, the student discourse was reexamined. At this point all of the student discourse was transcribed. This re-examination of the student discourse focused on the areas where students were reasoning about science concepts and attempted to determine commonalities among those sections. This analysis revealed that student reasoning about the science concepts throughout the inquiry investigation involved the development of explanations. Explanations appeared to be the key link between the students' inquiry investigations and their reasoning about the science concepts. Student discourse was then examined to identify general types of explanations that students were developing (Q2).

After characterizing the general types of explanations, a search of the literature was conducted to compare the types of explanations identified inductively from the data with prior descriptions of explanations. This search of the literature resulted in the development of a new theoretical framework based on explanations that could be applied to specific Claims-Evidence Inquiry activities. This theoretical framework was then used to examine the nature of the teachers' instruction (Q1) and student explanations linking claims and evidence in the inquiry reports (Q3). Analysis moved through iterative cycles of examining data, generating hypotheses, and searching for confirming and disconfirming evidence for conclusions.

Analysis of the Instruction (Question 1)

The first stage of data analysis involved a characterization of the instruction for each teacher during the water rocket inquiry. Following each day's observation a day-by-day description was created based on field notes and a review of the audio recordings of student and teacher discourse (See Appendix H for an example). The day-by-day descriptions consisted of identification of distinct instructional units, comments on what occurred during these units, and a preliminary coding of the nature of these units. Shifts in units were identified either by a shift in topic (i.e. designing investigations, collecting data, see Krajcik et al. 1998) or a shift in instructional type (i.e. whole class, small group).

A model of the key elements of claims-evidence instruction was created by open-coding teacher discourse and instructional artifacts from the two-week claims-evidence inquiry lessons, teacher handouts, and prior instruction. Initial coding was followed by sorting the codes into categories (macrocodes) that were then organized into themes based on the explanation framework described previously (i.e. explanations, claim, and inquiry) (Appendix I). The macrocodes identified key aspects of the instruction related to supporting students' development of explanations, understanding of the concepts related to the claim, and development of inquiry skills and understandings. Microcodes further described the nature of each key aspect of the instruction.

The teacher interviews were also coded to identify themes related to the teachers' beliefs about the important aspects of the instruction related to inquiry and the Claims-Evidence model (pre-instruction interviews) and their reflections on the instruction following the Water Rocket Inquiry (post-instruction interviews). Teachers' perceptions about the successes, challenges and possible changes to the Water Rocket Inquiry present additional evidence of the nature of the instruction that grounds this research.

This triangulation places the teachers' perspectives alongside the researcher's to increase the reliability of the conclusions drawn.

Analysis of Student Discourse regarding Explanations during Inquiry (Question 2)

Transcripts of the four target groups from the two classes and their written work were used as the data sources for this analysis. The combination of both the verbal and the written discourse allowed for an in-depth look at students reasoning about science concepts during all stages of inquiry. Analysis of the verbal and written transcripts consisted of identification of all instances where students proposed explanations. These were then coded to identify the stage of the inquiry process in which the explanation occurred. The explanations were then inductively coded to characterize the nature of the explanation.

A code list was created which consisted of macrocodes identifying the type of explanation (analogical, systems-based, and concept-focused) and microcodes that further described the nature of the specific type of explanation (Appendix J). For example, concept-focused explanations were further identified by the specific science concept that was being invoked in the explanation. Analogical explanations were given microcodes that identified the specific analogy that was being used. Microcodes for systems-based explanations identified the specific interactions between variables that were being invoked as explanations. For example, the following student explanation in italics was coded as Analogy - fuel. The macrocode of "analogy" identifies the type of explanation and "fuel" identifies the type of analogy employed in the explanation.

> Code: Analogy - fuel
> S_3: If you add more water, it will go farther.
> S_1: *Water equals fuel. Fuel equals longer, longer equals greater distance.*
> [TbGf, 11-1-05]

Analysis of Explanations Linking Claims to Evidence in Inquiry Reports (Question 3)

The main data source for this question consisted of written inquiry reports from students in five classes taught by Anne and three classes taught by Brenda. The first stage of analysis consisted of reading the analysis sections of all of the inquiry reports (total n=184). These inquiry reports were examined to identify if they referenced the claim in the analysis of the results. Inquiry reports that addressed the concept of momentum in some form were separated into "explicit" references to the claim and "implicit" references to momentum. In some cases the students referred to the claim as written, "the conservation of momentum affects the motion of an object" or referred to "the claim" in their analysis sections. These were coded as "explicit" references. However, in other cases students mentioned the concept of momentum, but it was not clear that they were referring to the claim or seeing their results as relating to the claim. These were coded as "implicit". For example, one student stated "The amount of momentum created by the air pressure leaving the rocket increases as water is added up to 1000 mL. This is because above 1000mL, not all of the water is able to be pushed out which increases the mass of the rocket."

The work samples that implicitly or explicitly addressed the claim were then transcribed and further analyzed to examine the nature of the connections that students made between the evidence and the claim. The work samples were identified with code numbers such as TB2044. The first two letters stand for the teacher's class (i.e. TB = Brenda's class). The first number stands for the specific class period and the last three numbers are an individual code assigned to each student.

Of the four inquiry questions investigated by students (Table 12) only two of the work samples in this analysis addressed the questions related to the density of the liquid in the rocket and none of them addressed the question related to the volume of the bottle. Due to the minimal data for these two questions, a decision was made to focus the following analysis on the water and mass of the nose question only.

These inquiry reports were inductively coded to examine the nature of the connection that students were making between their results and the claim. This resulted in four categories: (1) reports stating the claim without any connection to the results, (2) reports that suggested that the results supported the claim without any explanation related to the claim, (3) reports that included an explanation related to the claim but unconnected to the results, and (4) explanations which attempted to link the claim to the results (Table 9).

Table 9. Examples of the connections between the results and the claim

Nature of the Connection	Examples
No Connection	" **I don't know how to address the claim in a correct statement.**" [TB4005] "… **we had a claim that said, The conservation of momentum affects the motion of an object. To prove our claim right and do the investigation we made a question**. How does the amount of water affect the distance a water rocket travels? The amount of water affects the distance a water rocket travels because as you add more water it takes longest to launch into the air." [TB4028]
Results Support Claim, No Explanation Related to the Claim	"**Our results supported the claim because as we added more water to the rocket, it went further, but then decreased in distance. So it proves that the conservation of momentum affects the motion of an object.**" [TB4026]
Explanation, No connection to results	"The conservation of momentum affects the motion of an object in this experiment **because the momentum is never lost it is transferred which thrusts the rocket into the air.** My evidence supports my claim because it says that momentum affects the motion of an object. If an object has more mass meaning more inertia it is harder to get in motion. Creating a smaller acceleration causing the rocket to travel a smaller distance." [TB5002]
Explanations Attempting to Link Results to the Claim	"As the amount of water increased the distance increased until we added 1500 ml of water. Therefore, the conservation of momentum affects the motion of an object. The reason the water rocket went far until one point is **because we add more mass and the more mass the more momentum but the rocket couldn't have too much mass or it wouldn't go as far.**" [TB4019]

At this stage of the analysis, 45 of 184 inquiry reports were identified that included explanations attempting to link the results to the claim. Students' explanations were then displayed by translating the students' sentences into visual representations of the causal relationships between variables in the investigation (Appendix L). Causal representations were created by simplifying the written explanations into their key components. The key variables in the explanations were identified (i.e. water, mass, velocity, momentum, distance) and links between these variables were noted.

Figure 3 shows some examples of how the students' written analysis sections were translated into causal representations (Appendix L). A representation system was created to identify important components of the students' explanations. Some of the variables in this system (i.e. mass, momentum, velocity) could refer to the water or the rocket. In many cases, students did not clearly identify which they were referring to. However, when they did, this was noted in parentheses following the variable.

Key: a) = Explanations for increasing distance
b) = Explanations for decreasing distance
→ = Connection between two variables
Bold = Line of reasoning about momentum
Italics = Implied but not explicitly stated
[ ] = Supporting Statements or Qualifiers

w = water leaving the rocket
r = rocket
a = air pressure
g = ground

Example 1
"The momentum was conserved and it affected the motion of the water rocket. When more water was *added* there was more mass. More mass means there *will be* more momentum (unless you add too much). The water rocket went farther from 0 ml to 500 ml of water, then it didn't." [TB5009]

a)	**More Water →**	**More Mass →**	**More Momentum**	***More Distance***
b)		[unless too much mass]		*Less Distance*

Example 2
"With 0 ml the rocket *wasn't* heavy enough *to have* lots of momentum and just fell through the air. 1000 ml *gave the rocket* a lot of momentum and propelled it through the air with lots of force. With 2000 ml it *had* too much mass and *couldn't get* a lot of momentum to go far. With 0 ml the rocket wasn't heavy enough to get momentum, with 1000 ml the rocket had a lot of momentum, and with 2000 ml the rocket *had* too much mass *to have* lots of momentum." [TA5006]

b) No Water →	**Little Mass (r) →**	**Little Momentum (r) →**	***Little Distance***
a) 1,000ml Water →		**Lots of Momentum (r) →**	***More Distance***
		[Propelled through the air with lots of force]	
b) 2,000ml Water →	**Too Much Mass (r) →**	**Little Momentum →**	**Little Distance**

Figure 3. Examples of translation from written explanation to causal relationships

The results that most students got from their investigations showed an initial increase in the distance the rocket traveled and then a decrease. In order to clearly distinguish between the reasoning that students were using to explain the increase and the decrease, "a)" is used to identify the reasoning about increases in distance and "b)" is used to identify the reasoning about decreases in distance.

Links between variables are identified with arrows "→". In some cases relationships between variables were implied but not explicitly stated, in these cases the variables are represented in italics. This often occurred when students stated their conclusions such as 'as the amount of water increased the distance increased'. Then went on to explain this, but did not explicitly link their explanation back to the rocket traveling a greater distance. Based on the previously stated conclusion it was felt that this relationship could be implied and putting it in italics allowed for this to be distinguished from the students explicitly making this connection.

In cases where multiple lines of reasoning were expressed it was of interest to distinguish between the lines of reasoning that involved momentum and those that did not. Lines of reasoning that involved the concept of momentum are represented in bold font. In some cases students included supporting or qualifying statements that either added to the line of reasoning or qualified the conditions under which the reasoning held. These statements were placed underneath the line of reasoning in brackets.

Two examples will now be discussed to show how these representations are applied. To assist in seeing the connections between the student transcripts and the representations, the variables in the student transcripts are underlined and the links are identified in italics. In the first example, the student explicitly describes how increasing the water, would increase the mass, which would then increase the momentum. The adjectives “more” and “less” are included with the variables when the students make this distinction. This student also uses a qualifying statement, “unless too much mass” which is placed below the line of reasoning in brackets. In this transcript the explanations relationship to the distance the rocket traveled is implied from the students’ last statement, “The water rocket went farther from 0 ml to 500 ml of water, then it didn’t.” Because the relationship between the explanation and the distance the rocket traveled is only implied the distances are written in italics.

In example 2, the student displays multiple lines of reasoning related to the specific amounts of water that were tested. To represent this, each line of reasoning is represented on a separate line. In this case all of the lines of reasoning, except the supporting statement, “propelled through the air with lots of force” include the concept of momentum so these are represented in bold font. In this transcript the student is explicit about the rocket having more mass and more momentum, so these variables are identified with an “(r)” where this is clearly identified in the transcript.

In order to examine patterns in the student explanations, the elements of each causal representation were organized into columns so that the links between the independent variable (amount of water and mass of the rocket) and the dependent variable (the distance the rocket traveled) could be identified. The causal representations were then sorted into similar groups depending upon the question they were investigating and the links they included (See Appendix L). This allowed for the identification of patterns in the students explanations.

Analysis of Pre- and Post-Assessments (Question 4)

The assessments of students' content knowledge consisted of both multiple-choice and open-ended questions. The open-ended questions were scored by the researcher using a rubric (Appendix G). In addition, all information identifying the student, class, and version of the test were removed and the tests were randomized. This controlled for possible bias when scoring the tests.

Differences between the pre- and post-test were analyzed by statistical tests that utilized the paired nature of the data. In a few cases, students only took the pre-test or the post-test (Table 10). Students who only took one of the tests were excluded from the analysis.

Table 10. Students present for administration of pre-test and post-test

Teacher	Class	Only Pre-Test	Only Post-Test	Both Tests	Percent present for both tests
Anne	1	0	0	15	100%
	2	1	0	21	95%
	3	5	0	24	83%
	4	4	0	11	73%
	5	1	0	23	96%
Brenda	1	2	2	28	88%
	2	4	0	24	86%
	3	4	0	25	86%

Although an effort was made to provide students with ample time to take the test, limitations in the class schedules resulted in a number of students not answering all of the questions. When analyzing test results, questions that are left unanswered are often scored as zeros. If students' failure to answer the question was due to having read the question and not knowing the answer, then scoring it as a zero would be reasonable. However, if students' failure to answer the question was due to their not having enough time to complete the entire test, then scoring no answers as zeros could bias the results. This is especially a concern if the goal of the analysis is to compare two different test administrations in which students were given more time in one test administration than the other.

Table 11 shows the number of students who did not answer each question for the pre-test and the post-test. Examination of the distribution of no answers shows that the questions with the largest number of no answers occurred towards the end of the test. This suggests that students' failure to answer the questions may have been due to a lack of time rather than an inability to answer the particular question. However, the last three questions are more open-ended and possibly more difficult for students than the first 5 multiple-choice questions.

Table 11. Unanswered test questions

Questions		**Anne's Classes**					**Brenda's Classes**			**Total**
		1	**2**	**3**	**4**	**5**	**4**	**5**	**6**	
#1	**Pre**	0	0	0	0	0	0	0	0	0
	Post	0	0	0	0	0	0	0	0	0
#2	**Pre**	0	0	0	0	0	0	0	0	0
	Post	0	1	0	0	0	0	1	0	2
#3	**Pre**	1	0	1	0	0	0	2	0	4
	Post	0	0	0	0	0	0	0	0	0
#4	**Pre**	0	0	0	0	0	0	2	0	2
	Post	0	0	1	1	0	0	0	0	2
#5	**Pre**	0	1	3	1	0	0	1	1	7
	Post	0	0	0	0	1	0	0	0	1
#6	**Pre**	0	1	2	3	3	0	1	2	12
	Post	2	1	0	1	0	1	0	1	6
#7	**Pre**	3	6	4	3	3	1	1	2	23
	Post	2	1	0	1	2	0	1	0	7
#8	**Pre**	7	13	3	4	5	1	1	4	38
	Post	2	2	1	3	2	0	1	1	12

The distribution of questions that were not answered also shows that more students failed to answer questions on the pre-test than on the post-test. It is possible that this is due to students feeling more comfortable with the material when taking the post-test and therefore answering more questions. However, it is also possible that the difference between the pre- and the post-test was due to differences in time allotted to complete the test. If this was the case, then counting the unanswered questions as zeros could bias the comparison between the pre-test and post-test.

Based on this, the statistical analysis comparing the pre-tests and post-tests was conducted only on tests that contained answers to all questions. This reduced the total number of tests used in the analysis down to 116 for the total test, 72 for part I, and 66 for part II. Due to the differences between the questions in part I and part II, analysis of the data was conducted on the total test scores and on the questions in part I and part II separately.

The research question for this part of the analysis aimed to identify changes in students' content knowledge as a result of participation in the inquiry. The students in all 8 classes experienced the same curriculum related to the water rocket inquiry. However, it is likely that there could be differences between the teachers or in the distribution of students in the classes. Therefore, the data was first examined using one-way ANOVAs to identify any possible class or teacher effects. Paired t-tests were then conducted to identify changes between the pre-tests and post-tests. Paired t-tests were conducted on the total test scores, part I, part II, and the individual questions to identify any possible trends in the data.

CHAPTER IV
RESULTS

Introduction

To facilitate the presentation of the multiple aspects of this study, this chapter is organized in five sections. The first section, *Description of the Instruction*, presents a description of the water rocket inquiry task and the underlying science concepts. The second section, *Analysis of the Instruction,* provides a model of the key aspects of the claims-evidence instruction and their relationship to students' development of explanations, which answers the first research question in this study. The third section, *Developing Explanations – Student Discourse about Science Concepts during Inquiry*, examines when in the inquiry cycle students develop explanations and the nature of those explanations, which answers the second research question. The fourth section, *Student Explanations – Linking Evidence and the Claim*, uses student inquiry reports to specifically examine student explanations linking results to the claim and answers the third research question. The fifth section, *Assessment of Student Learning*, examines the results of a pre- and post-assessment of content knowledge given to students prior to and following the water rocket inquiry, which answers the fourth research question.

Description of the Instruction

The inquiry tasks that were the focus of this study involved using water rockets to examine concepts related to Newton's laws and momentum. The water rocket inquiry came at the beginning of the school year following a one-week unit on inquiry and the nature of science and a three-week unit on force and motion.

Description of Instruction Prior to the Water Rockets Inquiry

The teachers' instruction prior to the water rocket inquiry activity included instruction on inquiry and the nature of science and concepts related to force and motion.

General Instructional Sequences

The instruction during these units followed a general pattern in which new concepts were introduced by engaging the students in activities that allowed students to experience the concepts before terminology was introduced. These concepts were then often clarified through reading and class notes. This was then generally followed by review questions (Figure 4).

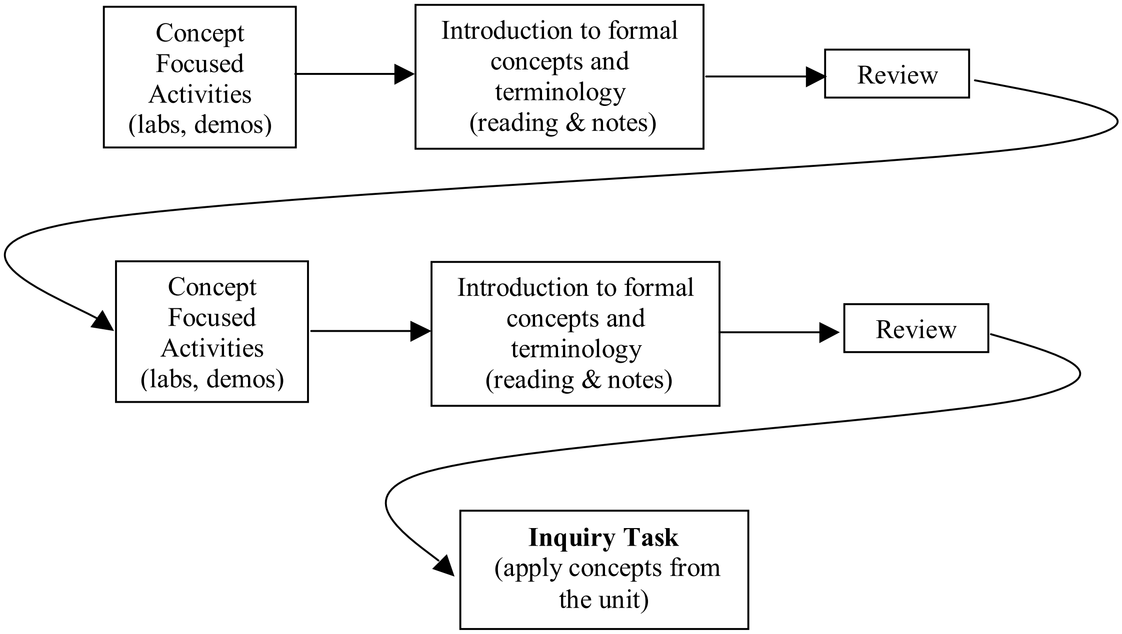

Figure 4. General instructional sequence

Within each individual activity the teachers also followed a general pattern in which students worked individually, then in small groups, and then student ideas were shared with the whole class through a teacher guided discussion (Figure 5).

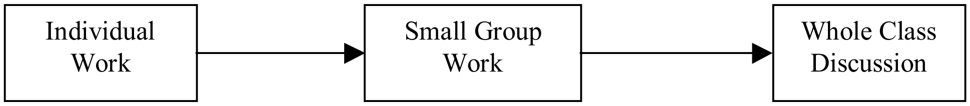

Figure 5. General activity sequence

Inquiry and the Nature of Science Unit

The teachers started the year with an 8-day unit that focused on introducing students to aspects of nature of science and scientific inquiry (See Appendix D for a description of the content and aspects of inquiry addressed in each activity). The activities in the unit focused on aspects of the nature of science including the difference between observations and inferences and the tentative nature of science. The activities also focused on understandings of inquiry including the relationship between explanations and evidence. Students also took notes on the nature of science, which focused on the relationship between evidence and scientific explanations and the tentative nature of scientific explanations. For example, the notes stated that "Scientific explanations are … based on evidence, shared with other scientists and the public, tentative and can change over time, connected to past explanations, not meant to answer all questions" (Class Notes, 9/19/05)

In the unit on inquiry and the nature of science the teachers also introduced the students to a model of scientific inquiry that would be used for the water rocket inquiries. This model describes inquiry as a cyclical process involving forming, designing, collecting, analyzing, and a return to forming. This model is largely based on the components of the Oregon Inquiry Scoring Guide (See Appendix A).

Force and Motion Unit

The force and motion unit leading up to the water rocket inquiry lasted approximately 15 days. This unit focused on concepts related to Newton's Laws, Momentum, and Gravity (See Appendix E for a description of the content and aspects of inquiry addressed in each activity). The unit began with an activity in which the teachers listed a number of words on the board related to force and motion and had the students write at least four sentences using the words. Students then conducted a number of activities related to Newton's 1st Law, Newton's 2nd Law, and Momentum. Following the activities for each major concept, the students read about the concepts in their textbook and took notes in class.

The activity titled, *Move it…Prove it*, occurred towards the beginning of the unit. In this activity, students observed a number of demonstrations that showed different aspects of Newton's Laws, Momentum, and Gravity. The demonstrations included the following:

a) Drop objects of different masses on balls of clay.
b) Drop a rubber ball on a counter.
c) Quickly remove an index card that is resting on a bottle and has a penny resting on it.
d) Two people standing on skateboards pull on a rope that they are both hanging onto.
e) Release an inflated balloon.
f) Drop a tennis ball, crumpled piece of paper, and flat piece of paper from same height and at the same time.
g) Roll a cart with a stuffed animal on it down a ramp and into a barrier.

Students made predictions about what they thought would happen and then observed the demonstrations and recorded what they had observed. The teachers had the students hold off on writing explanations for what they had observed until later in the unit after they had discussed the formal concepts. After the formal concepts had been introduced the students returned to these demonstrations and wrote explanations for them based on the science concepts they had covered.

Classroom Presentation of Momentum

The presentation of the concept of momentum is described in more detail because of the focus on this concept in the Student Inquiry. In the unit on Force and Motion prior to the inquiry activity, students took class notes on momentum, read a section in their textbook on momentum, and conducted a lab related to momentum called the Ramp of Ramming. During the Class Example Inquiry, the students took class notes on force and motion concepts related to the Water Rockets.

The class notes that students took (Figure 6) during the Force and Motion Unit focused on defining Momentum and the Law of Conservation of Momentum. Momentum was defined as (mass) x (velocity). Momentum was also described as the amount of inertia and the strength of an object's motion. The description of the Law of Conservation of Momentum described how momentum was transferred from one object to another when two objects collided. The notes also described how when mass is moving in one direction, its momentum is transferred in the opposite direction.

Momentum

- Amount of inertia
- Strength of an object's motion
- Momentum = mass X velocity (p = mv)
- Mass in motion creates momentum
- The more momentum an object has, the harder it is to stop.

The Law of Conservation of Momentum

- When a moving object hit another object, some or all of the momentum of the first object is transferred to the other object.
- When you get mass moving in one direction, the momentum is transferred in the opposite direction.

Figure 6. Class notes on momentum

Students also read a section from their textbook on Momentum. The textbook reading also emphasized the relationship between momentum and mass and velocity (Figure 7). When discussing the conservation of momentum, the textbook focused on the transfer of momentum for colliding objects and suggests that momentum stays the same whenever two or more objects interact.

- Momentum is a property of a moving object which depends on the object's mass and velocity. The more momentum an object has, the harder it is to stop the object or change its direction.
- Momentum is conserved when a moving object hits another object, some or all of the momentum of the first object is transferred to the other object. If only some of the momentum is transferred, the rest of the momentum stays with the first object.
- Anytime two or more objects interact, they may exchange momentum, but the total amount of momentum stays the same.

Figure 7. Textbook reading on momentum ("Holt Science", 2001)

In the Ramp of Ramming Lab, students ran a cart down a ramp and investigated how the cart affected the distance traveled by a ball that it hit. In part 1 of the lab, students changed the mass of the cart and measured how it affected the distance that the ball traveled. In part 2 of the lab, students changed the velocity of the cart by changing the slope of the ramp and measured how it affected the distance that the ball traveled. In this lab, distance moved was used as a measure of momentum.

During the Class Example Inquiry, the teachers presented class notes that introduced some of the relationships between rockets and Newton's Third Law and Momentum (Figure 8). These notes discuss the relationship between the momentum of the water leaving the rocket and the forward motion of the rocket.

Water Rocket Force and Motion

- Forward motion of rocket is equal and opposite in direction to the momentum of the water.
- Action: air has low mass and lots of energy that creates pressure that pushes on the water.
- Reaction: water has high mass and lots of inertia that pushes back on the air and the rocket.
- Downward motion of water creates momentum which depends on the mass and velocity of the water.

Figure 8. Class Notes on Water Rocket Force and Motion

Structure of the Inquiry Tasks

The inquiry tasks used by both of these teachers consist of four main components: forming a question or hypothesis, designing an investigation, collecting and presenting data, and analyzing and interpreting results. These four main components are based on the four sections of the Oregon Scoring Guide. However, the teachers further structured the nature of student expectations within each of these components (See Appendix K for a copy of Scientific Inquiry Work Sample Handout).

Figure 9 shows the general structure that the teachers followed in their inquiry tasks and the components of each section. In the section on Forming a Question or Hypothesis, the teachers started with a scientific claim. The claim was introduced to the students and then students were provided with a question or possible question that would be used to investigate the claim. Students then formed a hypothesis related to the claim and question and provided supporting evidence for their hypothesis.

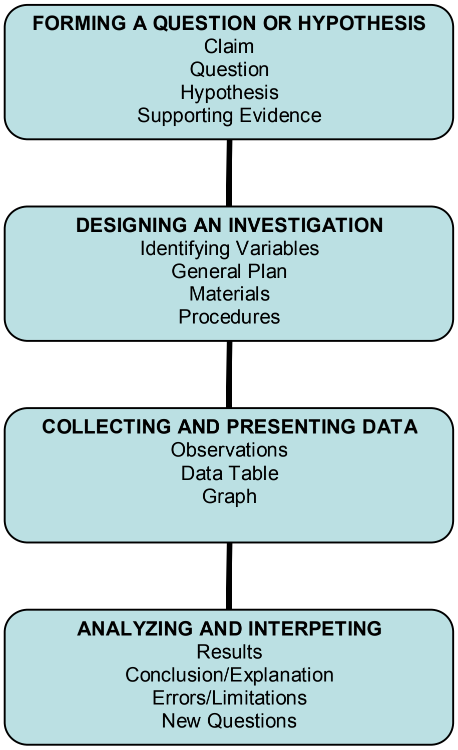

Figure 9. General structure of the inquiry task

In the Designing an Investigation section students identified the independent, dependent, and controlled variables. Prior to conducting the investigation, students developed a general plan for the investigation and described the materials they would use. After conducting the investigation, they wrote a detailed description of the actual procedure they followed.

In the Collecting and Presenting Data section students collected observations during their investigation, created data tables and recorded data, and translated their data into graphical representations.

In the Analyzing and Interpreting Results Section students reported their average results, formed conclusions related to the question and claim based on their results and formed explanations for their conclusions. Students also described possible errors and limitations from their investigations and suggested new questions that could be investigated.

Water Rocket Inquiry

The water rocket activity that is the focus of this study is based on an activity that Anne had been using for about 10 years. Three years ago she decided to modify it to fit the Claims-Evidence Inquiry Model. Prior to this modification, the students were basically free to ask any question they wanted related to water rockets. Students asked questions such as how the surface of the water rocket (i.e. covered with feathers or oil) would influence the distance it traveled. As the teachers began to focus this activity on specific scientific claims, they narrowed the questions that students investigated to ones which could be related to the claims and which could provide reliable data that could be interpreted for patterns.

Water rockets are constructed out of two-liter bottles that are filled with water and compressed air (Figure 10). The water rockets used in these classes were constructed by adding cardboard wings to a 2-liter bottle, placing clay on the nose of the rocket, and covering the entire assembly in duct-tape. An air compressor was used to fill the rocket with compressed air to a pre-determined amount. The rockets were launched at a 45-degree angle and the horizontal distance traveled was measured.

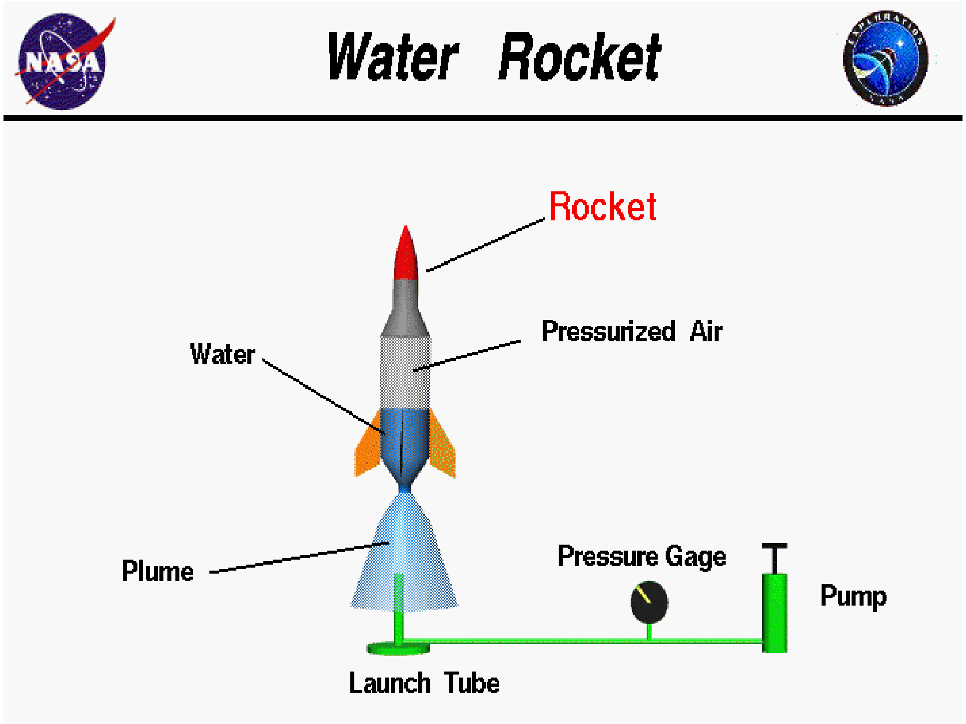

Figure 10. Typical water rocket set-up. (Image from http://exploration.grc.nasa.gov/education/rocket/rktbot.html)

The water rocket inquiry consisted of three main activities; initial launches, a water rocket class example using a claim about force, and a water rocket student inquiry using a claim about momentum (Table 12). Following the unit on force and motion students observed some initial launches of the water rockets. During these initial launches, the teacher launched a plain 2-liter bottle, a water rocket with just air, and a water rocket with some water in it.

Table 12. Sequence of activities during Water Rocket Inquiry

Sequence of Activities	**Description**
A. Initial Launches	Students observed the teachers launch a 2-liter bottle, a water rocket with just air and one with some water.
B. Water Rocket Class Example – Force	Students worked as a class to investigate the following claim and question. Claim – "The amount of force applied to an object affects the motion of the object" Question – "How does the amount of air pressure affect the distance of a water rocket?" (provided by teacher) Independent Variable – Air Pressure (0 psi - 30 psi) Controlled Variables – Amount of water, angle of launch, mass of rocket.
C. Water Rocket Student Inquiry - Momentum	Students worked in groups of 3-4 to investigate the following claim and one of the following questions. Claim - "The conservation of momentum affects the motion of an object" Questions – a) "How does the amount of water affect the distance of a water rocket?" (provided by teacher) Independent Variable – Amount of water Controlled Variables – Air pressure (psi), angle of launch, mass of rocket. b) "How does the mass of the nose affect the distance of a water rocket?" (provided by teacher) Independent Variable – Mass of the nose Controlled Variables – Amount of water, Air pressure (psi), angle of launch. c) "How does the density of the liquid in the rocket affect the distance of a water rocket? (developed by students) Independent Variable – Density of liquid (changed by adding salt) Controlled Variables – Amount of liquid in rocket, Air pressure (psi), angle of launch, mass of rocket. d) "How does the size of the bottle affect the distance of a water rocket?" (developed by students) Independent Variable – Size of the bottle Controlled Variables – Amount of water, Air pressure (psi), angle of launch, mass of rocket.

During the Water Rocket Class Example, the students worked as a class to investigate the claim, “the amount of force affects the motion of an object.” For this inquiry the whole class investigated how the amount of force affects the motion of an object by seeing how changing the amount of air pressure in the rocket would affect the distance it traveled. The air compressor used to fill the rocket with air allowed students to control the amount of air pressure that was put in the rocket.

During this inquiry, students were generally given time to discuss each section of the inquiry in their groups and then they came back as a class to discuss the class ideas. These ideas were summarized on the board for everyone to copy down. The students used a water rocket constructed by the teacher to collect data for this question and each group was responsible for one launch that would be added to the class data. During this phase the teachers modeled how the different sections of the inquiry should be completed. The students were given a handout for this inquiry that had select components already filled in to guide them in completing the inquiry (Appendix A). The teachers considered the class example as practice for the Water Rocket Student Inquiry. Students were not required to hand in their work from the class example, but they were allowed and encouraged to use it as a reference during the Water Rocket Student Inquiry.

Following the Water Rocket Class Example using the claim related to force, the students were then given a different claim related to the conservation of momentum, “The conservation of momentum affects the motion of an object”. During the Water Rocket Student Inquiry the students worked in small groups with less teacher guidance than during the Class Example. The students were given a handout that was very similar to the one they received during the class example, except that none of it was already filled out for them. The teachers provided little direct guidance to the students except for requiring them to have their work checked by the teacher at the end of each major section before they were allowed to continue. At the end of the inquiry, students typed up their work from the inquiry and submitted a final draft that was scored using the Oregon Scoring Guide.

In this inquiry students were allowed to choose a question provided by the teacher or develop one of their own. The two questions provided by the teacher were, "How does the amount of water affect the distance of a water rocket?" and "How does the mass of the nose cone affect the distance of a water rocket?" Students also came up with two additional questions, "How does the density of the liquid in the rocket affect the distance of the water rocket?" and "How does the volume of the bottle affect the distance of the water rocket?" Only 3 groups investigated the question related to density and one group investigated the affect of the volume of the bottle. Therefore, student data reports related to these questions are not included in most of the following analysis due to the limited amount of data.

For this inquiry students built their own rockets that would be used for data collection and were allowed to launch them multiple times. Groups generally launched their rockets between 9 and 12 times in order to test multiple levels of their independent variable and conduct multiple trials at each level.

Analysis of the instruction in this study looked at instruction prior to the inquiry, the Class Example, and the Student Inquiry. Analysis of student reasoning about explanations during the inquiry focuses on the Water Rocket Student Inquiry about momentum.

Applying the Concept of Conservation of Momentum to Water Rockets

In the Water Rocket Student Inquiry, the claim was "the conservation of momentum affects the motion of an object." Students were introduced to the concept of the conservation of momentum during the unit on force and motion. In this section, the science behind applying the conservation of momentum to water rockets will be discussed. In later sections the nature of the teachers' instruction related to these concepts and the implications for students' development of explanations will be analyzed.

In general the conservation of momentum states, "the total momentum of an isolated system of bodies remains constant" (Giancoli, 1991). Rocket propulsion can be explained in terms of the conservation of momentum. Before the rocket is fired, the total momentum of the rocket plus fuel is zero. As the fuel burns the total momentum remains unchanged. The backward momentum of the fuel, or water in the case of water rocket, is balanced by the forward momentum of the rocket. Since momentum is defined as the product of its mass and its velocity, the conservation of momentum as applied to a water rocket can be represented as the mass of the water leaving the rocket (m_w) times the velocity of the water leaving the rocket (v_w) is equal to the mass of the rocket (m_r) times the velocity of the rocket (v_r) ($m_wv_w = m_rv_r$) (Figure 11).

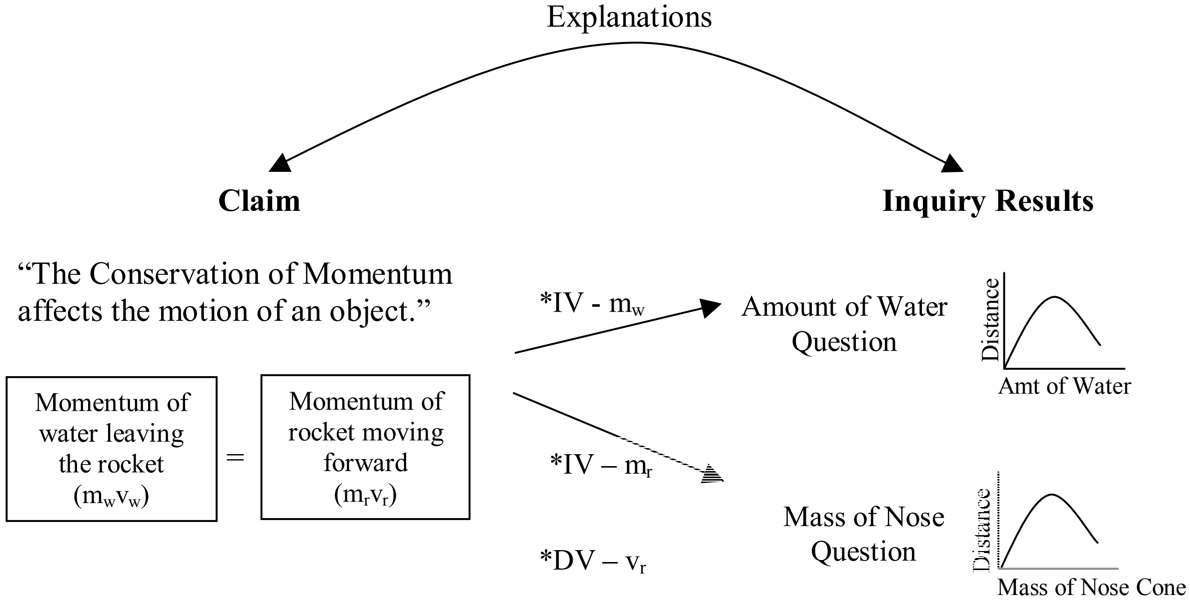

Figure 11. Model for the development of explanations in the water rocket inquiry (Water Question)

** IV - m_w signifies that the independent variable is related to the mass of the water (m_w).*
IV – m_r signifies that the independent variable is related to the mass of the rocket (m_r).
DV – v_r signifies that the dependent variable is related to the velocity of the rocket (v_r).

In most cases, the students investigating the water question found that increasing their independent variable resulted in an initial increase in the distance their rocket traveled and then a decrease in the distance as the independent variable was further increased. However, depending upon the range of variables the students investigated and the accuracy with which they conducted their trials, some of the results only showed an increase or a decrease. Some of the students investigating the mass question also found that the distance increased and decreased whereas others only found that it decreased.

Although water rockets appear fairly simple, the physics behind their flight is extremely complex. To truly explain the results of the water rocket investigations would require complex mathematics and the inclusion of concepts, such as drag and the center of gravity of the rocket, a concept that the students have not experienced. However, the primary interest in this study is how the student explanations relate to the claim, rather than whether or not the explanations consider all possible factors influencing the results.

Developing these types of explanations involves identifying the relationships between the results of the investigation and related science concepts. This involves two key components. The first component involves mapping the specific application to the concept. In this case, this involves seeing the conservation of momentum in the context of water rockets as a relationship between the momentum of the water leaving the rocket and the momentum of the rocket being propelled forward.

The second component involves relating the independent variable and dependent variable to the science concept. In the water rocket inquiry, the independent variables are the amount of water in the rocket and the mass of the nose cone. Increasing the amount of water in the rocket can increase the mass of the water leaving the rocket and therefore increase the momentum of the water leaving the rocket. In order for momentum in the system to be conserved, the momentum of the rocket then also increases. Since the mass of the rocket is constant, increasing the momentum of the rocket results in increasing its velocity, which results in increasing the distance it travels.

However, this relationship becomes more complicated as the amount of water in the rocket increases past about half full. As the amount of water increases, the volume available for pressurized air decreases and hence there is less stored energy available to push the water out of the rocket. At some point, not all of the water that is added is actually expelled from the rocket, decreasing the amount of mass leaving the rocket and therefore decreasing the momentum of the water. This can still be explained using the conservation of momentum. However, the key is to focus on the amount of water that is actually expelled from the rocket, not just the amount of water that is added.

Conservation of Momentum	$m_w \cdot v_w = - m_r \cdot v_r$
Water Question	$\uparrow m_w \cdot v_w = - m_r \cdot \uparrow v_r$
Mass Question	$m_w \cdot v_w = - \uparrow m_r \cdot \downarrow v_r$

Increasing the mass of the nose cone increases the mass of the rocket. Because the momentum of the water leaving the rocket stays the same, in order for the momentum to be conserved, the velocity of the rocket decreases in order for the momentum of the rocket to stay the same. As the velocity of the rocket decreases the distance the rocket travels should decrease. However, for students who investigated this question, some of them found that the distance the rocket traveled actually increased at first and then decreased. The initial increase cannot be explained using the conservation of momentum, but rather is likely due to changing the center of gravity which stabilizes the flight of the rocket when some weight is added to the nose of the rocket.

To further complicate the development of explanations for this question, the majority of the results that students received showed that the distance the rocket traveled increased and then decreased. This is not consistent with direct reasoning regarding the conservation of momentum. Explaining the initial increase involves considering mediating factors that are changing as the mass of the nose is changed. These include factors such as the center of gravity of the rocket. This was not a concept that the students explored and therefore it should not be expected that they would employ this concept in their explanations. Once again what is of interest in this study is how students relate their results to the concept of conservation of momentum.

This is a fairly simplistic model of the application of the conservation of momentum to these investigations. This model ignores how changing the independent variables influence factors such as drag and center of gravity. Although this model is not complete, it is a representation of the model provided by the claim and prior instruction regarding the concept of conservation of momentum and how water rockets work. A more detailed description of the prior instruction and its relationship to student reasoning will be discussed in a later section.

Analysis of the Instruction

Introduction

Examination of the instruction prior to and during the claims-evidence lesson in this study was used to identify the key instructional elements in the lessons and then to identify specific issues related to the relationship between the instruction and the students development of explanations. Multiple data sources including teacher discourse, handouts, and teacher interviews were used to characterize the instruction. A model of the teachers' instruction was created to identify the key instructional elements (Figure 12).

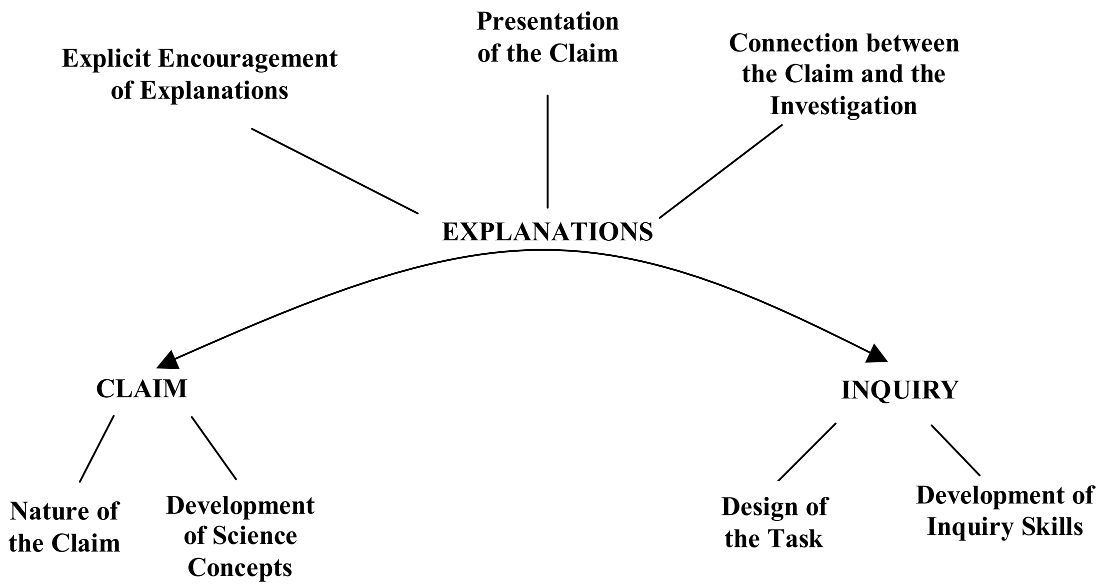

Figure 12. Key instructional elements related to the development of explanations in claims-evidence inquiry

The discussion of the instruction will be organized around three key aspects from this model related to supporting students in developing explanations during Claims-Evidence inquiry. The first aspect involves instruction related to the *Claim*, which includes the nature of the claim and the development of science concepts. The second aspect involves instruction related to *Inquiry*, which includes the design of the task and the development of inquiry skills and understandings. The third aspect involves instruction related to *Explanations*, which includes specific components of instruction that supported students in making linkages between their results and the claim. These include explicitly encouraging explanations, the presentation of the claim, and the connection between the claim and the investigation.

Instruction Related to the Claim

The development of student explanations linking the claim to inquiry results is influenced by the nature of the claim and the students understanding of the concept the claim is focused on.

Nature of the Claim

In Claims-Evidence inquiry the claim defines the theoretical concepts that students will use to explain their results. The claim plays a key role in determining the nature of the reasoning that students will be required to carry out in order to explain their results in terms of the claim. When teachers design claims-evidence inquiry tasks, they must make choices about the nature of the claim that they will use as the focus for the inquiry. Analysis of classroom observations and student’s written work highlighted the following issues related to the specific nature of the claim used to focus the inquiry: the relationship between the claim and the questions/task, the content complexity of applying the claim to the task, and language issues related to the wording of the claim.

The claims used in this study were related to force and the conservation of momentum (Table 13). The relationship between the first claim and the question that students investigated is fairly straightforward. The claim can be tested by changing the amount of air pressure, which changes the force, and measuring the affect on the distance, which is a measure of the amount of motion of the object. However, the relationship between the second claim and the questions students investigated is more abstract. In the second claim, students must do more than directly relate the independent variable from the question to a specific variable in the claim. Students are required to relate the independent variables from the question to the concept of conservation of momentum. This requires relating the amount of water and the mass of the nose to the momentum of the system, which includes the momentum of the water leaving the rocket and the momentum of the rocket moving forward. Although the two claims are worded very similarly, they require very different reasoning to identify the relationship between the claim and the evidence that will be gathered from the inquiry.

Table 13. Claims and questions

Inquiry	**Claims**	**Questions**
Class Example	The amount of *force* affects the *motion* of an object.	How does the amount of *air pressure* affect the *distance* the rocket travels?
Student Inquiry	The *conservation of momentum* affects the *motion* of an object.	1) How does the amount of *water* affect the *distance* the rocket travels?" 2) How does the *mass of the nose* cone affect the *distance* the rocket travels?

When considering the concept to be used for the claim one needs to consider not only the complexity of the concept, but also the complexity of applying the concept to the specific investigation that will be used to gather evidence for it. In this case, the concept of conservation of momentum is a concept that is covered in 8th grade textbooks and can be applied to the motion of a rocket. However, it is much more cognitively complex to apply the concept of conservation of momentum to changing variables in the rocket, such as the amount of water or the mass of the nose, than it is to generally explain the rockets flight in terms of the conservation of momentum.

For the student inquiry, the teachers' goal was for students to connect their investigations of water rockets to the concept of conservation of momentum. As Brenda stated to her students when introducing the claim "we're saying that conservation of momentum in some way, shape or form affects the motion of an object." This is a valid statement. However, by using the term "affects", the claim suggests a causal relationship between conservation of momentum and the motion of objects. It also suggests that conservation of momentum is a factor that can affect other objects rather than a concept that is used to explain the motion of objects in a system. This may have created confusion for students in making the link between the concept and their results.

Development of Science Concepts

The content instruction that occurred prior to the water rocket inquiry provided students with an understanding of the main concepts related to force and motion and gave them experiences with activities focused on these concepts.

Since the claim for the Student Inquiry is related to the conservation of momentum, it is important to more deeply examine the relationship between the presentation of momentum prior to the start of the water rocket inquiry and the nature of the reasoning required to apply the concept of momentum to the inquiry. Although students had covered material and conducted a lab on momentum there were some distinct differences between how the concept of momentum was presented in the prior instruction and the way that students would be required to reason about the concept of momentum when applying it to the water rocket inquiry (Table 14). Three key differences between the prior instruction and the water rocket inquiry were identified.

Table 14. Relationship between prior instruction about momentum and application of momentum to the water rocket inquiry

Prior Instruction	**Water Rocket Inquiry**
1. Conservation of momentum was discussed primarily in terms of transfer of momentum during a collision.	The water rocket involves an "explosion" rather than a collision. Reasoning about the water rocket requires reasoning about the total momentum of the system being equal to zero.
2. A direct relationship between momentum of an object and distance it traveled was implied.	This simplistic relationship broke down when applied to the rocket.
3. Distinction was not always made between the momentum of the components of the system being examined.	Reasoning about the results of the water rocket inquiry required differentiating between the momentum of the water and the momentum of the rocket.

The law of conservation of momentum can be applied to collisions between objects and certain types of explosions, such as in rocket propulsion. The prior instruction regarding the conservation of momentum focused primarily on the conservation of momentum for two colliding bodies. In the journal notes that students took there were two statements relating to the conservation of momentum. The first described what happens when one object collides with another object, "When a moving object hit another object, some or all of the momentum of the first object is transferred to the other object." The second statement suggests consideration of the vector aspect of momentum, "When you get mass moving in one direction, the momentum is transferred in the opposite direction." This description is applicable to the conservation of momentum for explosions, but is overly simplified for an application to collisions.

The textbook reading also focused primarily on the conservation of momentum for colliding objects. It described how momentum is conserved when a moving object "hits" another object, or anytime "two or more objects interact". The Ramp of Ramming lab that the students conducted on the conservation of momentum also focused only on the transfer of momentum for colliding objects. In this lab, students ran a cart down a ramp and recorded how this affected the distance that a ball hit by the cart traveled.

In the prior instruction, the conservation of momentum was often described as a linear cause-effect relationship in which one object collides with another causing its momentum to change. The presentation of the conservation of momentum was rarely described as a "system" in which the momentum stays constant. The only statement that comes close to describing the conservation of momentum in relationship to systems is from the text, "Anytime two or more objects interact, they may exchange momentum, but the total amount of momentum stays the same."

Reasoning about conservation of momentum in terms of transfer of momentum is reasonable in certain contexts. In some ways the momentum of the water leaving the rocket can be considered as being "transferred" to the momentum of the rocket. Following this line of reasoning when the momentum of water leaving the rocket increases, the amount of momentum transferred to the rocket increases, thereby increasing the distance that it travels. However, this line of reasoning breaks down when applied to changing the mass of the rocket. As described in an earlier section, adding mass to the rocket does not increase the momentum of the rocket because the momentum of the rocket is constrained by the momentum of the water. The linear cause-effect relationship implied by the idea of transfer of momentum breaks down when applied to changing the mass of the rocket. Reasoning about changing the mass of the rocket requires reasoning about the total momentum of the system.

The prior instruction also simplified the relationships between variables when presenting the concept in certain contexts. During the Ramp of Ramming lab on momentum prior to the inquiry, the teachers implied a direct relationship between the amount of momentum that an object had and the distance that it traveled, without discussing the relationship to velocity. By not explicitly discussing this relationship, students may have assumed that more momentum always means more distance. However, more momentum only means more distance if the velocity increases.

Furthermore, the questions in the Ramp of Ramming worksheet had students relate the change in mass or velocity of the car to the momentum of the object it collided with.

> *Example Questions from Ramp of Ramming Worksheet*
> "As the MASS of the car INCREASED, the DISTANCE the ball traveled ______________."
> "Momentum depends on the mass of the object; as the MASS INCREASED, the MOMENTUM _____________."

The relationship between changing the mass of the car and the increase in momentum of the ball is not discussed in terms of conservation of momentum. This simplification is not a problem as long as it is only the mass or velocity of the cart that changes (as was the case in the Ramp of Ramming lab). However, if the mass of the ball is changed, then this simplistic relationship no longer holds (i.e. as the mass increased, the distance would decrease). The simplification of the questions in the momentum lab could lead students to assume that when mass is increased, momentum always increases, and therefore distance always increases. However, in the case of changing the mass of the rocket, this is not true.

When discussing the relationship between the water rockets and momentum, the teachers were explicit about the relationship between changing the mass or velocity of the water and its impact on momentum, but implicit about the relationship between changing the momentum of the rocket and its relationship to distance traveled. For example, Anne asked students how they could make there be more momentum coming out of the rocket. The students suggested that they could add more air pressure. The teacher then expanded on this relationship by stating, "More air pressure, because that's gonna make the water do what? What's gonna increase? … It will increase the velocity. If the air is pushing on the water more, it will make it go faster. We use the same amount of water, so it's got the same mass. So we increase the momentum by increasing the velocity." However, neither of the teachers described how changing momentum of the rocket was related to the distance the rocket traveled.

In the prior instruction, a distinction between the momentum of different components of the systems was not always made. This was evident when the teachers described the relationship between momentum and water rockets in the Water Rocket Force and Motion Notes. The discussion of these notes came after students had collected data for the class example inquiry and before they wrote their analyses of the data. The notes were placed on an overhead for students to copy down and then the teachers explained the notes further in relationship to what they had experienced with the water rockets. The overhead notes described how the water leaving the rocket has momentum and how the forward motion of the rocket is equal and opposite to the momentum of the water leaving the rocket. The overhead notes did not specifically refer to the conservation of momentum and the description focused primarily on the momentum of the water leaving the rocket. In the notes only the water and not the rocket were referred to as having momentum.

However, the teachers' did expand on this in their verbal explanation of these notes. When the teachers discussed these notes they described both the momentum of the water and the momentum of the rocket and described how momentum was conserved. This can be seen in Anne's description of how momentum is related to the movement of the rocket.

> How much momentum is coming out of the back of the rocket? That is going to affect then, how much momentum the rocket has in the opposite direction, so the forward direction of the rocket is equal and opposite to the momentum of the water coming out of the rocket. … If I increase the momentum going this direction, I increase the momentum going in the opposite direction. So this is complicated, this is Newton's third law of motion, you've got opposite and equal reactions and we're dealing with momentum. Momentum of the water coming out is going to be conserved in the opposite direction. (Anne)

Brenda also further described how momentum was conserved. However, her description focused more on how momentum was "transferred" from the water to the rocket. In her discussion of the notes she stated that "If I have more momentum of the water pushing this way, we know that the momentum is not going to disappear so it is going to be transferred back to what object? … The rocket and the water rocket is going to go a greater or lesser distance? … Greater distance."

Being able to distinguish between the momentum of the water leaving the rocket and the momentum of the rocket moving forward was very important in terms of reasoning about the results of the Student Inquiry.

When asked about changes that the teachers would make to the inquiry before teaching it again in the post-instruction interviews, both teachers discussed their desire to be better able to prepare students to connect the concepts with the investigations. However, they struggled with how to prepare students while still providing a novel context in which students can apply the concepts.

> I still wish that there was a way to either preteach the content better or get them to see the connection between when they're changing something like the amount of water and the inertia and the momentum, you know how to make that clearer for everybody, not just the top 50% or whatever, but I don't know how to do that. … I mean part of it is supposed to be application, so it's supposed to be something new, something novel, something that they don't know, but then you need to teach them the things that they need to know to do that. (Anne, Post-Instruction Interview)

Brenda also expressed concerns about how the prior instruction on momentum prepared students to explain the water rocket inquiry.

> I like the idea of conservation of momentum, I think it's a great claim, I think it matches the inquiry, but I don't know that we covered momentum well enough and equated it well enough to rockets to get at that too much … I guess it was a hard connection. (Brenda, Post-Instruction Interview)

However, when Brenda discussed how she would make this better next year, she focused on making the students more familiar with the context (i.e. rockets) rather than addressing the actual presentation of the concept of momentum. She suggested that from the start of the unit they could use rockets as their example.

The teachers' comments in the interviews suggest that they are aware that the students are struggling to apply the concept of momentum that they have learned to the water rocket. However, their comments focus on superficial issues related to the students' difficulties with the application. Anne focused on students being able to relate the change in water to momentum and Brenda focused on students needing to be more familiar with the rockets. Analysis of the relationship between the reasoning required to explain the results of the water rocket inquiry and the presentation of the science concepts in prior instruction suggests that the issue may not be one of familiarity as much as a deeper issue related to the way in which the concept is applied.

Interviews with the teachers also suggested that their own understanding of the concepts might have influenced their ability to recognize the differences between applying the concept in the prior instruction and in the water rocket inquiry. In the post-instruction interview, when Brenda was explicitly asked about the relationship between how the conservation of momentum was presented in prior instruction and how it was applied in the water rocket inquiry, she stated that it was the same. When asked to explain, she expressed a common misconception about the "transfer" of water from the rocket to the ground and back to the rocket. She described how momentum was transferred from the cart to the ball in the lab they did on momentum, the Ramp of Ramming, and how water was transferred from the water to the ground and back to the rocket in the water rocket. She sees both contexts as involving the "transfer" of momentum from one object to another. However, she describes the water rocket as harder to conceptualize for kids because it is "not as a direct visual connection." (Post-instruction interview) Her own misconception about how momentum relates to the rocket appears to have influenced her view of the relationship between the prior instruction and the application of the concept to the rockets.

Students development of explanations related to the claim involve reasoning about the results of their investigations within the conceptual framework that they hold related to the concept that is a focus of the claim. Examination of the relationship between the reasoning that was required to apply the concept of momentum in the prior instruction and the reasoning required to apply the concept in the inquiry suggests distinct differences. The results of this analysis suggest that simplifications in applying the concept in one context may limit students' ability to reason about the concept in a new context.

Interviews with the teachers suggested that they struggled with how to determine an appropriate degree of transfer between the prior instruction and the inquiry. They tended to focus on superficial aspects related to the concept when considering how to prepare students for the inquiry, rather than examining the nature of the reasoning that was required in the different contexts. They both recognized that students needed to have some background knowledge of related concepts but struggled with how to determine the degree and the nature of the transfer that should be required to reason from prior understanding of the concepts to the inquiry.

Instruction Related to Inquiry

Students' development of explanations involves student reasoning about the predictions and/or results of the inquiry. The design of the task and the students' skills and understandings about inquiry will influence the predictions and results for which they are developing explanations.

Design of the Task: The Importance of Consistent Data and Clear Patterns

The nature of the task influenced the type of data that students collected from their investigations and the nature of the reasoning that is required to develop explanations about the results. In most cases during this study, the questions that students investigated provided consistent enough data to identify patterns and trends for which they could attempt to provide explanations.

The questions identified by the teachers in the Class Example and the Student Inquiry provided consistent data with distinct enough differences between data points to produced clear patterns. In the Class Example, students investigation of the relationship between air pressure and distance traveled produced a clear linear relationship in which increasing the air pressure increased the distance the rocket traveled. In the Student Inquiry, most students investigating the water question found a fairly clear pattern that showed that as the amount of water in the rocket increased, the distance increased and then decreased. The results of the mass of the nose question also produced fairly consistent results that showed either an increase and decrease or primarily an increase.

The clear patterns shown in these results allowed students to identify possible causes and develop explanations. These results can be contrasted with the results that students received who were investigating how the density of liquids affected the distance the rocket traveled. In this investigation the distances that the rocket traveled for the different levels of the independent variable showed only slight differences and therefore determining whether the density of water had an impact on the distance the rocket traveled was difficult. Since the results were unclear it was difficult for students to develop explanations for the results.

In the pre-instruction interviews, when asked about the teacher's role in inquiry and the factors they considered when designing tasks, both teachers emphasized the importance of having tasks that provided consistent data that the students could make sense of. The teachers described how it was important for the students to have reliable data that showed a trend in order for them to be able to develop explanations related to the science concepts at the end of the inquiry.

When asked about the teacher's role in inquiry, Anne described how the scaffolding of the inquiry experiences was important so that students were able to collect good data.

> So I think early on the biggest mistakes I made teaching inquiry were making it so open-ended that they asked a really stupid question or questions that didn't get good data or questions that ended up leading to a misconception about a concept. So I think getting to the point where this is gonna get them good data that's gonna confirm this concept …, then that's, that's probably been the key for me. (Pre-Instruction Interview)

Development of Inquiry Skills

In order for students to successfully conduct their inquiry investigations and get results for which they can develop explanations, they must have the necessary skills and understandings about inquiry. The teachers in this study carefully structured prior experiences for the students in order to support them in developing the necessary skills needed to successfully design an experiment, collect data, and analyze data.

The teachers provided opportunities for students to practice these skills during the Force and Motion Unit and the Water Rocket Class Example. A number of activities during the Force and Motion Unit not only covered concepts related to force and motion, but also included inquiry skills such as predicting, making measurements, graphing, and interpreting patterns (Appendix F).

The Water Rocket Class Example also provided students an opportunity to practice the various stages of a full inquiry that was very similar to the one they would be expected to conduct more independently during the Water Rocket Student Inquiry. During the Water Rocket Class Example, students received more guidance about how to complete sections of the inquiry. For example, in the Water Rocket Class Example, the hypothesis, controlled variables, data tables, and parts of the analysis were started for them so that they had a model to follow during their first experience conducting a complete inquiry task.

Students were also given handouts that described how to correctly set up a data table and how to graph different types of data. The teachers also had students practice measurement skills specific to the Water Rocket Inquiry, such as using a meter tape for measuring distance, a volumetric cylinder for measuring water and an air compressor gauge for measuring air pressure.

In the pre-instruction interviews, both teachers emphasized the importance of supporting students in developing the necessary inquiry skills in order to successfully conduct the inquiry and make sense of their results. This perspective was expressed in response to multiple interview questions including questions about what inquiry looks like, the teachers' role in inquiry, and challenges in inquiry teaching.

Both teachers emphasized the importance of teaching skills so that students could be successful when conducting their inquiries. Anne emphasized the importance of checking in with students to make sure that they were collecting accurate data in order to have data that they could actually analyze when they finished. Brenda emphasized the importance of preteaching the skills that students needed to be successful rather than just assuming that they would be able to figure it out.

> It's a lot of prep, you know, preparing kids to be successful, so making sure they, you know that if we want them to make a graph that we've at least gone over that instead of just kind of expecting them to miraculously know. Which I think for a long time, inquiry was like that. Let's see what you can do then let's use this scoring guide to score you, when we haven't really prepared you for it. Or at least that's how we did it for a little while. (Brenda, Pre-Instruction Interview)

> In middle school I think probably one of the biggest things is skills. Having skills to measure and collect data, observe, individual basis for the skills and then how to pull that together to actually learn something new… (Anne, Pre-Instruction Interview)

When asked about the teacher's role in inquiry teaching, both teachers described the importance of providing modeling and structure prior to and during the students' inquiry experiences. The teachers described how they often model the process for students by going through an example inquiry with the class prior to having the students conduct their own in small groups. The teachers also emphasized the importance of providing students with experiences in which they could gain the skills and background content knowledge that they would need to be successful during the inquiry. Anne described the importance of providing students with

> … a lot of really guided scaffolded experiences so that they learn the right sort of systematic ways of doing things. Especially with a lot of the measurement skills, because their measurement skills …, are terrible. So creating those experiences so that they learn those skills… (Anne, Pre-Instruction Interview)

Brenda's responses in the interviews also suggested that she struggled to integrate inquiry experiences for students focused on developing skills with inquiry experiences focused on developing conceptual understanding. Although both teachers described how inquiry teaching could be a way for students to learn new science concepts. Brenda seemed to describe inquiry that focused on process and inquiry that emphasized knowledge construction as two different types of inquiry.

> I feel like there's kind of two facets, there's the inquiry where they're really trying to construct meaning and figure it out and then there's the inquiry that's focused kinda on the process of forming a question and stuff like that

> and so I feel like that's two different types of things… (Brenda, Pre-Instruction Interview)

She describes exploration inquiry activities that may occur first and allow students to develop their conceptual understandings of the topics. Then she describes how those conceptual understandings can be used to engage in the process of inquiry and answer a question. When she was asked to describe whether these occur at the same time or not, she stated that,

> They kind of occur in conjunction, a lot of times the exploration inquiry activity occurs first and as kind of a way to get kids you know to kind of look at their conceptions and misconceptions of things and then as we kind of teach through some of the concepts then at the end we kind of end up more looking, we have a conceptual base built and then we go through more of the process, let's take a question that maybe we can answer using some of our knowledge and then the emphasis, the emphasis is finding the answer to the question, but I think sometimes in all of the things that have to be done, background information and all of that stuff, the kids start to see it more as a process as opposed to oh I'm trying to answer my question, because there's a lot of work to be done and I think that's hard, yeah, I don't know. I don't think it's bad, but I think it's, it's not the exciting I get to explore and do whatever unstructured thing that I want. (Brenda, Pre-Instruction Interview)

In this study, the teachers carefully structured experiences for students in order to prepare them to collect accurate data and present their data in a form that allowed for identification of patterns and trends. In the interviews, both teachers emphasized the role of students' inquiry skills in allowing them to successfully conduct the inquiry and make sense of their results.

Explanations: Linking the Inquiry to the Claim

Explicit Encouragement of Explanations

Students generally engaged in developing explanations during two phases of the inquiry: while developing supporting evidence for the hypothesis and when explaining their results. During these phases of the inquiry, the teachers provided explicit instructions that encouraged students to develop explanations.

Supporting Evidence

During the Forming a Question and Hypothesis section, the teachers specifically guided students to move beyond merely proposing hypotheses to specifically providing supporting evidence for their hypothesis. This required students to develop explanations for their predictions. This was clearly outlined in the handout the students received. The written instructions asked students to "write down information you already know that is **relevant** to the **claim, question**, and **hypothesis**" (bold in original handout) and then provided space for students to describe "scientific facts, ideas, and concepts" and "personal experiences" (Appendix K).

Analysis of teachers discourse during the inquiry also showed that teachers' instruction provided students with guidance on what should be used as supporting evidence and how supporting evidence should be linked to the hypothesis. Teachers' instructions emphasized that students should use both scientific concepts and personal experiences to support their hypotheses. In regards to scientific concepts, the teachers encouraged the students to use their classroom notes to identify scientific concepts that they had learned about in the preceding unit that were relevant to their hypotheses. When referring to personal experiences, the teachers encouraged students to use both prior classroom activities and non-school related personal experiences to support their hypotheses.

The teachers also emphasized that just identifying related scientific concepts and personal experiences was not enough. The teachers emphasized the importance of using these scientific concepts and personal experiences to explain why they made a particular prediction in their hypothesis.

> You have to explain how, how does the law, how does the concept, how does the fact, support your hypothesis. (Anne, Student Inquiry)
>
> You need to have good evidence that includes an explanation of how the laws and concepts tie in. Don't just list the laws and say, first law, second law, third law. You must tie in, tell me why it proves your hypothesis true. Same with your personal experience. (Brenda, Student Inquiry)

During the class example the teachers had the students work in small groups to discuss possible supporting evidence for their hypotheses and then led a large group discussion in which students shared their ideas and teachers helped clarify the nature of the supporting evidence that they were using. In these discussions, teachers clarified students' responses by connecting them to specific concepts and probing them to clarify how their supporting evidence related to the independent and dependent variables in their hypotheses.

During this discussion, both teachers used the strategy of elaborating on student responses in order to explicitly connect their explanations to specific concepts. For example, in the following transcript Anne asks students to share some of the supporting evidence that they came up with.

1 Student: Ah, since for every action there's an equal and opposite reaction, if there's more air pressure, there's a bigger action, so it means there has to be a bigger reaction.
2 Anne: So according to Newton's third law of motion for every action there's an equal and opposite reaction. You're saying that more air pressure is like having more of an action.

In this transcript, the student has described how one of the science concepts they have learned about is related to their hypothesis. The teacher elaborates on this by naming the specific concept that the student is referring to, Newton's Third Law.

In Brenda's class a similar interchange took place in which the teacher elaborated on the student's response in order to explicitly connect the concept to the students' explanation. This is shown in the following transcript.

1 Student: Well it's because more air pressure added makes it the more faster the air's gonna push the water our of the back [inaudible].
2 [Teacher is interrupted by other students talking and S repeats what he said]
3 Student: The faster the water comes out of the rocket the faster the acceleration it's gonna go [inaudible] acceleration.
4 Brenda: So you're saying that the second law applies. You said second law right because acceleration? … Second law, acceleration will increase, because you're saying there's a greater force?
5 Student: Yeah.
6 Brenda: As there's more air pressure, there's more force pushing the water out, because air pressure creates greater force.

In this transcript, the teacher links the student's explanation to a specific concept, Newton's Second Law, and more explicitly links the concept to the hypothesis and the claim by adding the relationship between acceleration and force.

Another example from Anne's class shows how the teachers' elaboration explicitly linked both the independent and dependent variable to the concept. In the following transcript a student suggests that Newton's second law is relevant to their hypothesis that increasing the air pressure in the rocket will increase the distance that it travels.

1 Anne: Anybody have anything either different or something to add to that as supporting evidence, other piece of supporting evidence?
2 Student: Newton's second law.
3 Anne: How does Newton's second law apply?
4 Student: The acceleration of an object depends on its force, [inaudible] force so it will accelerate more.
5 Anne: So you're saying that more air pressure is like adding more force …
6 Student: Yeah.
7 Anne: …and therefore it's gonna accelerate more. And do you think more acceleration will make it go farther?
8 Student: Yeah.

The teacher then further probes the student to explain how that law is relevant. The students' initial explanation does not clearly connect the concepts of force and acceleration to the investigation of air pressure. So the teacher expands on the students' response to explicitly make the connection between force and air pressure and acceleration and distance.

The teachers also encouraged students to not only identify personal experiences that were related, but to also explain how these personal experiences supported their hypothesis. In the following transcript, from the Class Example Inquiry, a student suggests that a prior activity that they did with balloons supports the hypothesis. Anne then questions the student about what they learned from the activity and what variables were being changed in order to more clearly identify the relationship between the balloon activity and changing the air pressure in the rocket.

1 Anne: Okay, personal experiences. Who has a personal experience that supports this hypothesis?
2 Student: That balloon.
3 Anne: So what did we learn from that one?
4 Student: Action reaction.
5 Anne: So what did we add more of when we did that activity?
6 Student: Air.
7 Anne: We added more air, so more air made it go farther. So we've already seen an example where when we add more air to something which is similar to air pressure the object travels a farther distance in the opposite direction.

These discussions provided explicit examples of how students should link the scientific concepts to their hypotheses. However, the nature of the discourse during these discussions shows that the teachers tended to be the ones making these connections, rather than engaging the students in further developing their explanations. For example, in the following transcript a student suggests that Newton's third law is related to their hypothesis and then Brenda uses questioning to elaborate on the connections between Newton's Third Law and the hypothesis.

1 Student: I thought kind of three, Newton's third law because for every action there is an opposite and equal reaction thingy. Like cause as the water or the fuel like comes out it pushes the rocket up.
2 Brenda: So as we add more force to the air pressure in there, what is the action, is it going to be stronger or less with more air pressure?
3 Student: Stronger.
4 Brenda: It's going to be stronger, so the action force is going to increase with pressure, which means what will happen to the reaction force that pushes the rocket forward. Is that going to be stronger or weaker as the action force increases?
5 Student: Stronger. …
6 Brenda: The rocket pushing it forward and if it pushes forward with more force is the distance gonna be greater or less?
7 Student: Greater.
8 Brenda: Greater. Ok, so the water pushes the rocket with more force. Is that the action or the reaction?
9 Student: Reaction.
10 Brenda: Reaction force which equals greater distance.

In this transcript the questioning consisted primarily of the teachers elaborating on what the students said and asking them simple questions about the relationship between the hypothesis and the concept. All of the teachers' questions were either or questions that required only single word answers. These discussions provided students with models of how to link their hypotheses to the concepts, but did not necessarily provide them experiences with engaging in the reasoning that would be required to make the connections themselves.

The teachers further emphasized the importance of clearly connecting the concepts to the investigation during their interactions with individual groups during the Student Inquiry. As the students worked through each section of the inquiry, the teachers required that the students have the teachers check their work before moving on to the next section. After completing the first section, teachers often asked students to more clearly describe the relationship between their supporting evidence and the question. In the following transcript, Brenda is reading over the supporting evidence in the TbGf group. At this point the girls have listed a number of concepts that they found in their classroom notes that they felt were relevant to the question, but they had not described how they applied.

> 1 Brenda: OK, cause downward motion of water creates momentum, which depends on mass and velocity of water. So if I'm adding more water, how is that going to affect my momentum? I need a little bit more expansion on some of these. You guys have a really good start. I'm gonna stamp um, but I'm seeing some gaps in them still. I see some good starts, but I don't see how it ties back to your hypothesis. I see, ok here's a concept that I know applies, but I'm not seeing the connection. You know what I mean. So you're saying, downward motion of water creates momentum which depends on mass and velocity, so which one of these are you changing by adding more water? Mass or velocity?
> 2 Student: Mass.
> 3 Brenda: OK. So things like that I need expansion of. I want to know how does action reaction apply to this situation. You know what I mean. Instead of just saying action reaction, what is the action reaction? Ok, so I think if you can discuss just a little bit more for that then you can go on to the next section.

In this transcript, the teacher tells the students that they need to make the connection between these statements from the classroom notes and their hypothesis more explicit. She provides an example of this connection by questioning them about how the concept they have identified relates to the independent variable in their investigation. Having these checkpoints during the Student Inquiry allowed teachers to check students supporting evidence for their hypothesis and encourage them to not only identify the concept, but also to use the concepts to explain their hypotheses.

When discussing the requirements of the Oregon Inquiry Scoring Guide for the Forming a Question or Hypothesis section the teachers emphasized the importance of the background information being clear and complete. The teachers interpreted the term "complete" to mean that the students needed to make a clear link between the scientific concept and their investigation. This further encouraged the students to use the scientific concepts to explain their hypotheses.

> 1 Brenda: Alright, last one, question or hypothesis and background are clear and complete. Ok, this is where I take off the most passing scores. This will knock you from a four down to a three in about 2 seconds. Let's say you started to say something about Newton's third law, you said third law explains how water rockets work. Is that complete or incomplete?
> 2 Student: Incomplete.
> 3 Brenda: Incomplete, because I don't know how it explains it. If you even attempt to explain to me how, that can bump you up to a four, but if you just leave it halfway done or incomplete I'm not gonna be able to give you a four, so really make sure you complete your thoughts. OK, this is one of the hardest sections to pass, even more hard than the analyzing part I guarantee it, so please make sure your information is important and please make sure it is complete, finish it, ok.

After discussing the scoring guide the teachers provided the students with a fictitious work sample that the teachers had written up that the students could use as an example. Brenda's discussion of this further emphasized and modeled what a "complete" explanation of their supporting evidence should look like.

> Brenda: Notice in the supporting evidence, I know you guys read through this, they completely explained how Newton's third law applied. They talked about then also how Newton's second law applied to how the force was changing and thus the acceleration was changing. It was a complete explanation. If you guys give me an explanation pertaining to your question like this it is guaranteed I will give you a five, because it is complete, it is connected, and it is using the laws correctly.

Although the majority of inquiry-based instructional materials have students make hypotheses before beginning investigations, few of them require students to explicitly describe their reasoning for their predictions. In the classrooms of these two teachers, this particular component provided an important context for students to develop explanations and engage in preliminary discourse about the validity of these conjectures.

Explaining Results

In the analysis section of the water rocket inquiry, students were required to describe their results, draw conclusions, and explain their results. The emphasis on not only drawing conclusions, but also explaining results led to students attempting to make explicit links between the claim and other science concepts and their results. In the section on Analyzing and Interpreting Results, the task instructions explicitly asked students to "**Explain** how your **results/evidence** support the **claim** using **scientific concepts, facts** and **ideas**" (Appendix K).

In developing explanations for results, the teachers focused primarily on having students use scientific concepts. When discussing how the scoring guides would be used to grade their analysis sections Brenda stated that, "the first thing it says in there is use scientific knowledge. Ok, so you need to put what you know about Newton's laws, about momentum, about gravity, whatever else you know about scientific laws that might apply to force and motion of rockets, you need to use those thoughts and then explain what happened."

When the teachers discussed the analysis section with students they emphasized the same key features of explanations as they presented when students were developing explanations for their hypotheses. These included explicitly identifying the science concepts they were using in their explanations and connecting their explanations to the independent and dependent variable of the investigation.

The following transcript shows how Anne emphasized these aspects of explanations when discussing students' explanations for the Class Example inquiry.

1 Anne: Who thinks they have a good explanation for why this happened? Why does the water rocket go farther when we add more air pressure?
2 Student: Um, because there was more air pressure so there was more force and so since there's a bigger force that means there has to be a bigger reaction or action and since there's a bigger action there has to be a bigger reaction.
3 Anne: Because there was more force, there was a bigger action, therefore there had to be a bigger reaction. And you might want to expand this in terms of, so the force was the air pressure and what was the reaction, the distance that it traveled. So you could also add that this was an example of Newton's third law of motion. For every action there's an equal and opposite reaction.

In line 3, Anne rewords the students' explanation and writes it on the board for students to copy down. As she rewords it she emphasizes the connection to the independent and dependent variables, "And you might want to expand this in terms of, so the force was the air pressure and what was the reaction, the distance that it traveled." She then explicitly connects the explanation to Newton's third law.

When discussing the requirements for getting a passing score on the Analysis section of the Oregon Inquiry Scoring Guide the teachers emphasized the importance of using scientific concepts correctly. However, the inquiry scoring guide played an interesting role in downplaying the necessity of the accuracy of student explanations. A passing score of a four on the Analyzing and Interpreting Results section of the Oregon Inquiry Scoring Guide requires that the student work sample "uses scientific terminology with minimal errors to report results and identify patterns, and attempts to propose explanations." (See Appendix A)

When Brenda discussed the requirements for getting a passing score on the analysis section of the scoring guide she said, "the key that I see here that is pretty important is to try to explain. To get a four do you have to have an exactly accurate explanation? … No, but do you have to have a complete explanation? …Yes, so if you give me a complete explanation that at least in some way correctly employs scientific concepts even though it might not be 100% correct that's still a passing score." She went on to emphasize that students needed to use their scientific knowledge correctly, but that their explanations did not need to be perfect, "If I start talking about one law and call it another that would be a major error in my book, because you are not using your scientific knowledge correctly. So you need to attempt to explain and maybe no, maybe it's not as good as a scientist could explain it, but as long as you use the laws correctly and you give it your best shot, that is a four (passing score)."

The emphasis on "attempting to propose explanations" encouraged students to propose explanations even if they weren't entirely sure about the accuracy of the explanation.

In the post-instruction interviews, the teachers were asked to reflect on how the inquiry supported students in formulating explanations from evidence. The teachers felt that the inquiry encouraged almost all of the students to attempt to formulate explanations even if the quality of their explanations varied. Brenda stated, "I think we do an ok job with that, again I think that our explanations are dependent sometimes on where kids are cognitively, but they all, they all, most at least try and explain, you know what happened" (Post-instruction interview).

When reflecting on possible changes to the water rocket inquiry for next year, Brenda also suggested that integrating more modeling of explanations in the prior instruction could enhance the instruction they provided. She described how the analysis sections in most of the labs during the Force and Motion Unit consisted of primarily fill in the blank questions. She suggested that more of those sections could be used to practice the development of explanations, "I think that we could have engaged, or maybe we should have engaged more discourse around let's explain why this happened." (Brenda, Post-Instruction Interview).

Analysis of the inquiry showed that the teachers provided modeling and explicit prompts for students to develop explanations during multiple stages of the inquiry. In addition, Brenda's reflection on the instruction points to the importance of not only providing prompts and modeling, but also providing opportunities for students to practice generating explanations by engaging in discourse related to making sense of phenomena in multiple contexts.

Presentation of the Claim

The way the teachers presented the claim set the stage for how students would see the purpose of the investigation in relationship to the claim. The teachers emphasized three aspects related to the claim. First, teachers focused on claims being based on and well supported by evidence. Second, the teachers emphasized that the claims were known to be “true”. Third, teachers emphasized that the claim was being used to “frame” their investigations.

The emphasis that each teacher placed on these aspects varied. Anne emphasized that claims are supported by evidence. In the introduction to the class example inquiry she stated that “…the way that we’re gonna collect more evidence to support this claim is by answering this question, ‘how does the amount of air pressure affect the distance of a water rocket.’”

Brenda focused more on the investigation being “framed” by the claim. For example, when introducing the class example inquiry, Brenda stated that

> “…the claims that I will choose to be kind of the overriding theme of our investigation will be ones in this case that are proven scientific claims. Could somebody read, what is our claim that we are going to use to frame our investigation?”

The way in which the claim is presented has implications for how students see the link between their results and the claim and ultimately the nature of the explanation that they develop to link those concepts. If the purpose of the investigation is to gather evidence to test the claim, then it suggests a greater link between the results and the claim than if the purpose of the claim is to “frame” the investigation. If the purpose of the claim is to “frame” the investigation then it suggests that the investigation should be relevant to the claim, but not that the investigation or interpretation of results needs to be directly linked to the claim.

Both teachers emphasized that the claims that they were investigating were “true” claims. When the teachers were asked about the key components of the Claims-Evidence model in the pre-instruction interviews they emphasized the role of starting with a claim for which students could gather evidence and connect to their analysis. The teachers viewed the claim as a way to focus student investigations on specific science content that they wanted the students to know. The teachers chose claims that were scientifically accurate and focused on the science content the students had previously studied. Anne described how, “For me, it's providing them with the claim that I want them to confirm, because that's the content that we've been learning …" Brenda also described the importance of choosing an accurate claim and presenting it as something that is scientifically accepted, "… we teach it [the claim] as something that is true or it could be something that is false, but we always do a claim that is, at least up until now we have done a claim that is true, and so the kids then come back to that hopefully throughout their background information and throughout their analysis…"

The teachers' responses in the pre-instruction interviews suggested that they felt a need to emphasize the scientific correctness of the claim in order for students to interpret their results in ways which supported scientifically consistent understanding of the concept. However, in the post-instruction interview Brenda reflected on the possibility that the emphasis that they had placed on the claims being "true" claims may have de-emphasized the importance of evidence to the students.

> We've been kind of teaching it as something that is true, something I could look up in a book and make sure that I know is true and so you're less likely to gather evidence of something you already know is true sometimes or see the urgency with which to do that … at least if they were able to start doing them along the way as their own they could see, maybe start to develop that connection between why evidence to support it might be important. (Brenda, Post-Instruction Interview)

Brenda also stated that she might try introducing claims in prior activities during the Force and Motion Unit and allow students to create some of their own claims. She felt that having students investigate some of their own claims might help them see the importance of connecting the evidence to the claim.

The presentation of the claim has implications for how students see the purpose of the investigation and the role of evidence in investigating the claim. This in turn influences students' development of explanations linking the results (i.e. evidence) to the claim.

Connection between the Claim and the Investigation

If student explanations are to link the results of their investigations to the claim then students must see the connection between the claim and the investigation. The teachers in this study did this in two ways, by explicitly connecting the claim to the questions and by explicitly requiring students to link their analysis to the claim.

Connection between the Claim and the Question

The first link between the claim and the student's investigations involves the connection between the claim and the questions or hypotheses that are a focus of the investigation. The teachers provided students with a handout that guided them through the steps of the water rocket inquiry. This handout explicitly asked students to relate their question and supporting evidence for the hypothesis to the claim. This handout was used for both the Class Example and the Student Inquiry.

> **FORMING A QUESTION OR HYPOTHESIS**
> *(From the Handout for Water Rocket Scientific Inquiry Work Sample, emphasis in original)*
>
> **CLAIM** (Write the **claim** for which **evidence** will be gathered.)
> **QUESTION** (Write a **question** related to the above **claim** that can be **answered** by **gathering data** in a scientific investigation.)
> **HYPOTHESIS** (Write a **hypothesis** that can be **tested** by **gathering data** in a scientific investigation.)
> **SUPPORTING EVIDENCE FOR HYPOTHESIS** (Write down information you already know that is **relevant** to the **claim, question** and **hypothesis**.)
> .

The teachers also described the relationship between the question and the claim when discussing the instructions for the water rocket work sample. For the class example, both teachers provided students with the question that they would use to investigate the claim. However, the teachers varied in the extent to which they made this connection explicit. Anne implicitly connected the question to the claim by stating that "the way that we're gonna collect more evidence to support this claim is by answering this question, 'How does the amount of air pressure affect the distance of a water rocket?'"

In contrast, Brenda explicitly described the link between the question and the claim. The following transcript shows how Brenda explicitly walked the students through the links between the claim and the question that she had chosen for them to investigate.

1 Brenda: How does the amount of air pressure affect the distance of the water rocket? So I want to look at my question and see, does it tie into my claim. First question I want to know, is I know my claim is talking about the amount of force put on an object, in my question, what is it that I am using to change the amount of force?

2 Student: Air pressure.

3 Brenda: The air pressure, so check, I have something in my question that's going to influence force, air pressure. Now I want to make sure that I'm looking at how force affects the motion of a particular object. In my question I'm changing air pressure to affect the force. What is, is there something that I'm looking at the motion, and what object's motion am I looking at in regards to my question, how am I looking at the motion and what object am I looking at motion in?

4 Student: [inaudible]

5 Brenda: The distance of the water rocket. So the object is the water rocket, what does that make distance?

6 Brenda: Okay, if something is going a certain distance is it moving? So I'm looking at my question, I'm saying do I have something that indicates that I'm changing the force. Do I have something an object I'm looking at's motion? Do we have both of those parts?

7 Brenda: Yes. It's a good question, it makes, it fits with our claim.

In this transcript Brenda explicitly connects the concept of force to the independent variable of air pressure in the question (line 1). She then relates the motion of the object to the distance that the rocket travels (line 5). In line 6 she then reemphasizes the two key connections between the claim and the question.

For the Student Inquiry the teachers provided the students with two questions to choose from or allowed them to choose their own question. When the teachers introduced the questions for the group inquiry, they focused on how these two questions were chosen because of knowing that they would give really good data and only implicitly described that these questions were related to the claim. For example, Anne stated, "So based on my experiences there are two questions related to this claim that give you really good data, that will help you, that will allow you to analyze that data well." She then went on to state, "Those two changes, the mass of the nose cone and … amount of water, really give you some interesting data related to this claim about the conservation of momentum". The connection between the claim and the questions was implied, but there was no discussion of clearly identifying how they were connected.

When the teachers discussed the option of allowing groups to choose their own questions, the focus remained on whether or not the question would give good data and whether or not the students had a well thought out plan about how to answer the question. There was no discussion of whether or not the questions actually related to the claim.

Student discussions related to choosing the question were analyzed to examine the nature of their discourse and if their discussions of the question they chose related in any way to the claim. Since the questions were given to them in the class example, these discussions only occurred in relation to the Student Inquiry. Of the four focus groups, three of them chose the question about the amount of water and one group chose the question about the mass of the nose. The TaGf and TbGf groups engaged in very little discussion about which question to do and provided little justification for why they chose that question, except for one of the girls commenting that she wanted to do the mass of the nose because “it sounds fun”. The discussion about the question among the students in the TaGm group focused around which question would be easiest versus which one wasn’t already being done by other groups. The TbGm group spent a lot of time discussing which question to do, but the discussion mainly focused around two boys in the group arguing for one question and one of the other boys arguing for the other question, until the one boy finally gave in and agreed to do the other question. Neither side provided a justification for why they wanted to do that particular question.

Since the teacher chose these questions, the students may have just assumed they were related to the claim and/or felt no need to discuss their relationship to the claim. Unfortunately no audio was recorded of groups who chose to do questions that were not provided by the teacher to examine whether or not their discussions about which question to do incorporated any consideration of the relationship of the question to the claim. However, observations of Anne’s interactions with one group who chose to investigate a question besides the two provided by the teacher, suggested that neither the students nor the teacher considered how that question related to the claim. The question involved investigating how the density of liquid in the rocket would affect the distance the water rocket traveled. Changing the density of the liquid would influence the momentum of the liquid leaving the rocket and would directly provide evidence related to the claim. However, the researcher did not observe the teacher or the students discuss this relationship.

If the question is related to the claim then students should be able to explain their hypotheses in terms of the claim. The Water Rocket Inquiry handout implied that students should link their supporting evidence to the claim. However, the teachers were inconsistent about explicitly emphasizing this connection when discussing the supporting evidence.

When introducing the Student Inquiry, Brenda introduced the claim and asked students what they had already seen that might provide evidence for the claim.

1 Brenda: Object, so we're saying that conservation of momentum in some way, shape or form affects the motion of an object. So if momentum is conserved, in some way that is going to affect the motion of another object. Can you guys think of any examples that we could say to prove this claim true right now? We know it's true, but we've seen some things already that can give us some evidence that this is actually true. …
2 Student 1: A car hitting a car.
3 Brenda: Car hitting a car. The momentum of one car hits the other and its conserved and its changing the motion of that one that takes off, ok very good.
4 Student 2: [inaudible]
5 Brenda: Yeah, [Student 4] is talking about, have you ever seen those balls, that they're connected to a bar and they hit back and forth. That's all about conservation of momentum and they affect the motion. I want you guys to think really carefully in terms of this claim as we think about water rockets. We talked yesterday about how water rockets have a lot to do with the conservation of momentum. The water has mass and its moving at a velocity, does that give it momentum?
6 Student: Yes.
7 Brenda: Yes it does and if momentum is conserved then that momentum should have some sort of effect on what objects motion? If the momentum of the water is conserved and is not lost, what object's motion is that momentum affecting?
8 Student: Forward.
9 Brenda: What does it propel forward?
10 Student: The rocket.

In this transcript, Brenda used the students' examples to explicitly link them to the claim (line 3 and line5) and to remind them to think about the claim when doing the Student Inquiry (line 5).

However, in most of the other instances when the teachers were talking about supporting evidence for the hypothesis, the connection between the claim and the supporting evidence was not made explicit. When discussing the supporting evidence for the Class Example students often explained it by referring to force, which implied a connection to the claim, but the teachers did not make this connection explicit.

Furthermore, when the teachers discussed the final draft requirements they gave examples that stated the claim, but did not make an explicit link between the claim and the question, hypothesis, or supporting evidence. For example, Brenda provided students with an example of the Forming a Question or Hypothesis section of their reports by stating,

> So you could start off the paragraph saying something like, have you ever wondered how far a water rocket would fly if you could change the amount of water? In our investigation, our group decided to investigate the claim, how does conservation of momentum affect the motion of an object. So there's my claim. We then went on to ask the question, how does the mass of the nose cone affect the distance? There's your question. We thought that if you increase the amount of mass on the nose cone then the distance would do blah blah blah. (Brenda, Discussion of final draft requirements).

In this transcript, the claim, question, and hypothesis are stated, but the connection between them is not discussed.

Since the questions were provided to the students they were also not engaged in examining the nature of the evidence that would be gathered to test the claim. The students were allowed to make some decisions about the design of the investigation, such as what range of values to test for the independent variable and how many trials to conduct. However, these decisions did not require reasoning about what counted as evidence in these investigations.

In the post-instruction interviews, the teachers were asked to reflect on how the inquiry supported students in giving priority to evidence in order to develop and evaluate explanations. The teachers felt that the students understood that they needed evidence to base their conclusions on, but that they may not see their data as evidence.

> We talked about evidence, but I don't feel … that I did … a very good job of showing kids the value of evidence in science, like I think they know that their data should support their conclusion, but they don't equate their data as evidence. (Brenda, Post-Instruction Interview)

This suggests that Brenda recognizes that the inquiry instruction failed to develop students' understanding of the role of data as evidence for testing claims.

Connection between the Claim and the Analysis

In the analysis sections of the Water Rocket Inquiry, the teachers guided the students in linking their results to the claim both through guidance provided by the handout and through verbal instructions for the analysis section of the inquiry reports. In the analysis section of the handout students were explicitly asked to link both their conclusion and explanation to the claim.

> **ANALYZING AND INTERPRETING RESULTS**
> *(From Handout for Water Rocket Scientific Inquiry Work Sample, emphasis in original)*
>
> **RESULTS** (Describe the evidence you gathered by using your specific data to state your **average results**.)
> **CONCLUSION** (State your **conclusion** by answering the **question** and addressing the **claim**. Include **patterns** and **trends** suggested by the average data.)
> **EXPLANATION** (**Explain** how your **results/evidence** support the **claim** using **scientific concepts, facts**, and **ideas**.)
> **REVIEW YOUR DESIGN** (Describe some possible **limitations** of your procedures or equipment and any **errors** in your data that may have prevented more accurate results in the investigation.)
> **NEW QUESTIONS** (Write new questions you have about force and motion based on your results.)

In the Class Example Inquiry, the handout further modeled how to link the results and the claim by providing sentence starters for the students to fill in. For example, in the conclusion section the teachers provided the start of a conclusion that both stated the results and linked the results to the claim, "As the amount of air pressure increased, the distance traveled by the water rocket _________. Therefore, as the force applied to the water rocket increased, its motion also _________."

During the Student Inquiry the teachers reemphasized the importance of linking the conclusions and explanations to the claim. For example, when discussing the requirements for writing explanations Brenda stated that “So we’re going to talk about how does it, (explanation) relate to the claim, remember that the claim is, how does the conservation of momentum affect the motion of an object. So how does that help explain why your water rocket traveled more or less distance according to whatever, how you changed your variables.” Brenda further emphasized this when discussing the scoring guide that would be used to grade the analysis sections of their projects, “I cannot emphasize enough, and it’s hard. I know it’s sometimes hard to kind of understand how to do it, I need you guys to really think back to your claim.”

Anne also discussed the importance of linking the conclusion and explanations to the claim when discussing the requirements for writing up their final project. In terms of the conclusion, she stated, “You’re then going to state your conclusion by answering the question and addressing the claim … so everybody should be talking about the conservation of momentum and how it affects the motion of an object.” In terms of writing the explanation, she emphasized explaining the link between the results and the claim, “explain how your results are evidence to support the claim. So why did your data support this claim, does it have to do with this claim?” However, when Anne discussed the Oregon Inquiry scoring guide that would be used to grade their work, she did not mention the need to link their results to the claim. The Oregon Scoring Guide does not include any specific wording about claims. It is possible that contrast between the teachers handouts which require linkages between the conclusions/explanations and the claim and the Oregon Scoring Guide which does not could have caused confusion about the importance of making this link.

In the pre-instruction interview, when the teachers were asked about what aspects of the Claims-Evidence inquiry model they believed influenced students understanding of science concepts they emphasized the role of the claim in allowing the students to better connect their analyses to science concepts. The teachers described how the Claims-Evidence Approach appeared to help students connect their analysis to the science concepts more than in previous types of inquiries they had done.

> In the past when they get their data, and then they're just like 'it went farther because like I don't know' and now it's like 'well my claim says that momentum affects how far something goes, that has something to do with momentum, ok, what's momentum, mass and velocity, I changed the mass, oh I must of increased the momentum'. So I think it makes the connections more explicit, I think it makes them more explicit. (Anne, Pre-Instruction Interview)

> I feel like the main difference between Claims-Evidence and regular inquiry is just having the claim and having that connection between the claim and the evidence or the analysis that you're giving or the background information. Just really being able, I think it helps them in some respects be able to tie in scientific concepts better as opposed to just personal experience, because if the claim is a true claim and it includes some scientific concepts that have been covered up to that point then I think if it's at least proposed to the question they feel like they have more access or more ability to use that, kind of like a license to say, 'oh, ok, I get it, I can try to explain that using this concept (Brenda, Pre-Instruction Interview)

Anne further described how the Claims-Evidence approach differed from their previous inquiry instruction where students' inquiries just started with a question.

> I think it's just having that statement, that you're not starting with a question, because oftentimes, I think when kids write questions, sometimes, they ask a question like, they might word it, you know 'does the mass affect how far the rocket goes and then they're just like, well yeah it does, more mass makes it go farther or not as far' and they just don't, they tend to just not connect it back to anything. (Anne, Pre-Instruction Interview)

The teachers believed that the claim played a key role in assisting students with connecting their analyses to science concepts and provided explicit prompts to support them in making these connections.

Developing Explanations: Student Discourse about Science Concepts during Inquiry

Student discourse during the small group inquiry was examined to determine when student discourse about science concepts occurred and to describe the nature of that discourse. The framework used to examine student discourse focused on students' development of explanations during the inquiry. For this analysis, explanations were defined as a causal account of how or why something happened or would happen (Horwich, 1987). The discussion of these results will start by describing when students engaged in developing explanations during the inquiry. Then the nature of the explanations will be discussed, including three main types of explanations employed by students.

Development of Explanations Occurred Primarily When Supporting Predictions and Explaining Results

Student discourse related to science concepts occurred during all four stages of the inquiry. However, the majority of the verbal discourse related to science concepts occurred during the Forming a Question or Hypothesis section and the majority of written discourse occurred during the Forming a Question or Hypothesis section and the Analyzing and Interpreting section (Table 15).

Table 15. Occurrence of explanations during inquiry stages

Inquiry Stages	Type of Discourse	
	Verbal	Written
Forming a Question or Hypothesis	Common	Common
Designing an Investigation	Limited	N/A
Collecting and Presenting Data	*Limited	N/A
Analyzing and Interpreting Results	Limited	Common

*Based on field notes of the entire class, not the focus groups.

Forming a Question or Hypothesis

During the Forming a Question or Hypothesis section, students posed hypotheses related to their questions and developed explanations for their hypotheses. These explanations occurred both as a part of their reasoning about the predictions they made and from specific prompts from teachers to provide supporting evidence for their hypotheses. Explanations during this phase of the inquiry were common in both the students' verbal and written discourse.

All four of the focus groups engaged in verbal discourse related to developing explanations during this section. For three of the groups the nature of this discourse was extensive and involved the discussion of various explanations. The nature of these discussions will be examined in more detail in the following sections. One of the groups, TaGf engaged in more limited discourse in this section. In this group, the discourse was guided by one student who provided an explanation that the other students then wrote down. The following transcript shows an example of this discourse. In line 2, the student states her explanation. Then in lines 4-6 she restates it slowly so the other students in the group can copy it down.

TaGf, 10-27-05

1 S: What are you putting for supporting evidence?
2 S1: I said, so for inertia, the tendency of an object to continue doing what it is doing, therefore the more mass, the rocket will want to stay resting longer and as it starts to move it will want to move, it will want to stay in motion longer as well.
3 S: …write all that down?
4 S: OK, inertia…say inertia is or I?
5 S1: [inaudible]
6 S: The tendency of an … object to…

In this group the discourse related to explanations was more limited and generally guided by one student in the group.

Designing an Investigation

During the Designing an Investigation section, some of the students in the focus groups engaged in the development of explanations when discussing their ability to control variables, the range of data they would collect, and when discussing the reasoning behind their ideas for how the rocket would be constructed. For most of the groups these discussions were very limited and consisted of one or two comments. However, the TaGm group engaged in extended discussions involving explanations during this phase of the inquiry. Students' written discourse in the inquiry reports for this section consisted solely of a description of procedures without any explanations for why the procedures were carried out in a particular way.

When discussing what variables would be controlled in the experiment, the TaGm group discussed how they couldn't control the air pressure or the mass, because they were affected by changing the amount of water in the rocket. For example, TaGmS1 explained that "No, the mass isn't going to be the same because we have different amounts of water in there."

When discussing the range within which they would vary the independent variable, students in two of the groups (TaGm and TbGf) argued that they couldn't fill the bottle all the way with water. Their explanations for this focused on the relationship between increasing the amount of water in the bottle and the amount of air pressure in the bottle. The nature of these explanations will be discussed in more detail below.

When discussing how they would construct their rocket, some students engaged in developing explanations related to how the shape of the rocket would affect the distance it traveled. The explanations were related to the shape of the nose, the smoothness of the rocket, how the weight was distributed on the rocket, the size of the bottle, and the number of wings the rocket had. For example, students in the TaGm group had an extended discussion about how many wings they should put on the rocket. In the following transcript, students discussed whether one wing, 3 wings or no wings would be best and based their explanations on whether or not the rocket would spin and whether or not spinning was a good thing or not.

1 S_3: It would go the furthest with one that goes down. It would make it steady.
2 S_1: No it wouldn't.
3 S_2: That would make it spin, if you put one wing?
4 S_1: If you put 3.
5 S_3: One wing, straight down like this…
6 S_2: Yeah, that would spin.
7 S_3: …and it would go straight with one wing.
8 S_1: If you put 3, it would.
9 S_3: It's supposed to spin.
10 S_2: No, it's not.
11 S_3: Yeah, like a bullet, you know how it spins and goes farther and more accurate.
12 S_1: But it doesn't have any wings, bullets don't have any wings.
13 S_3: Like a football, it spins.
14 S_2: Yeah, but does a football have wings on it?
15 S_3: You could put wings on it and it would go a lot further.
16 S_2: I'll put wings on it and it won't spin.
17 S_3: Yeah it would stabilize it. Yeah, you could make the wings like this and it would have it spin.
18 S_1: Have you ever noticed how bullets don't have wings?
19 S_3: Yeah they have wings cut in them that go like this, engrave, we could line up paper around it so it's like an engraving.

Collecting and Presenting Data

During the Collecting and Presenting Data section, students engaged in developing explanations when they launched their rockets and made observations of the distance that their rockets traveled. Due to the active nature of the rocket launches, it was not possible to audiotape the student discourse during the launches. However, field notes were taken and students were observed during the launches engaging in developing explanations for unexpected results that occurred during their launches. Many of the students who were investigating the water question expected the rocket's distance to increase as the amount of water in the rocket increased. However, as the rocket was filled approximately more than half full with water, its distance began to decrease. Students were overheard talking about how it must be going less distance because it was heavier.

Analyzing and Interpreting Results

During the Analyzing and Interpreting Results section, students developed explanations for their results while writing their conclusions and explanations. Although the majority of students discussed conclusions and possible explanations for their results in their inquiry reports, very little verbal discourse occurred in the small groups related to conclusions and explanations. Students' discussions of their results focused primarily on how to calculate averages and graph the data. Two of the groups mentioned the explanations and only one of the groups actually engaged in discussion about their conclusions and explanations during class time.

Students in the TaGm group mentioned the section on results but engaged in very limited discourse related to the explanations. Only two instances were identified in the transcripts when explanations were mentioned. In one instance, the students stated that they were working on the section on explanations, and one student asked, "S: Hey on, uh, number 3, what does that have to do with Newton's Law? Never mind" (TaGm, 11-4-05). However, this comment did not lead to any actual discussion about the explanations. The following day the students were reviewing each others inquiry reports and one student made a comment about how another student forgot to compare their results to a law and focused on how it would get a better grade if it was compared to a law. There was no discussion of the reasonableness of the explanation.

TaGm, 11-7-05
1 S_2: You didn't, you forgot to compare it to a law.
2 S: Yeah.
3 S: It would get a better grade.

In contrast, two of the boys in the TbGm group engaged in extended discourse about how momentum related to their results. During this discussion they struggled with how momentum related to the rocket (line 1-3), how this related to the distance the rocket traveled (line 5), and interactions between the water and the compressed air (line 7-8). The following transcript shows the initial conversations these two boys engaged in related to explaining their results.

TbGm, 11-10-05

1 S_2: So wouldn't the water and air be like the momentum of the rocket? The water would be like the momentum of the rocket.
2 S_1: Yeah, I was thinking both.
3 S_2: Both, yeah like the air…
4 S_1: Cause, I mean…
5 S_2: … and then that like affects the distance of the rocket.
6 S_1: Yeah.
7 S_1: I have a question; no it's not like a question I need to know I was just wondering. OK, so the air when it's moving into the rocket does it just like go through the water.
8 S_2: Yeah, like it like…You can't compress the water, so the air just kinda goes like through the water and sits at the top.

Only one of the other boys in this group was present on this day and he primarily worked individually on the graph and did not engage in the discussion about the results.

Overall, few students in the focus groups engaged in verbal discourse related to explaining their results. When reflecting on the instruction in the post-instruction interview, Brenda also recognized that students' engaged in very little discourse in their groups about the actual results of their investigations. She reflected on how the unexpected results provided students an opportunity to reason about the science concepts and make sense of what was occurring in their investigation, but that most students came back in from the launches and sat down and worked individually without discussing their results or their explanations for the results with other students. She stated that she would try to come up with ways of better facilitating the discourse during the analysis section of the inquiry, "because I think that is really, the more I think about it the more valuable I think that could be in helping, especially those lower end kids work their way somehow towards an explanation that is somewhat scientifically related, building their confidence in that" (Brenda, Post-instruction interview).

Three Main Types of Explanations

Examination of the nature of the explanations that occurred during these different sections of the inquiry, suggested that students were developing three types of explanations: analogical explanations, systems-based explanations, and concept-focused explanations. This discussion focuses mainly on the students' verbal discourse. However, the written discourse was also examined and used to verify the three types of explanations found in the verbal discourse. These three types of explanations will be discussed separately, but did not necessarily occur independently. Students sometimes used multiple types of explanations in conjunction when explaining objects or events.

Analogical Explanations

Analogical explanations occurred when students used analogies (either from personal or classroom experiences) to explain predictions and results. The analogies students used to explain their results and hypotheses consisted of analogies from both classroom and personal experiences. Figure 13 shows the types of analogies that students employed in explaining their hypotheses. These analogies all came from the three groups investigating the water question. The most common personal experience that students used as an analogy was related to fuel or gas in a car. Other analogies from personal experience included reactions of vinegar and baking soda, shaking pop, and stepping on a water bottle filled with water and air. Students also used prior classroom experiences as analogies to explain their predictions. Most of these analogies consisted of references to prior water rocket launches they had observed, including the initial launches and the launches from the class example inquiry.

- Personal Experiences
  - Fuel, gas in car
  - Vinegar and baking soda
  - Shaking Pop
  - Squashing a water bottle with water & air
- Classroom Experiences
  - Watching prior water rocket launches
  - Balloon Zoom

Figure 13. Analogies used in explaining hypotheses

These analogical explanations occurred when students were explaining or providing supporting evidence for their hypotheses. Primarily they occurred in response to the teachers' instructions and handout that required students to provide "personal experiences" as supporting evidence for their hypotheses.

In one case it was noted that the students' use of an analogical explanation occurred spontaneously after stating her hypothesis as a way of explaining her hypothesis. This can be seen in the following transcript in lines 3 and 5. This student continued to use this explanation in later discussions and in her written report.

1 S_1: What do you think will happen? I think that the more amount of water it will go farther.
2 S_3: [Interrupts S_1] If we add more water then the distance of the rocket will be greater. It's like my…
3 S_1: Because like if you added more fuel and like uh…
4 S_3: It's water.
5 S_1: …or something, it lasts for a longer time.

Students varied in the extent to which they connected their analogies to the actual hypotheses that they had made. In some cases, the analogies that students used as supporting evidence were only superficially related to the hypothesis. In these cases, the students referred to related experiences, but the experiences were not really used as explanations. In other cases, the students clearly described how the analogies supported and explained their hypotheses. The following statement from S_3 in Anne's class included both forms. In the Forming a Question or Hypothesis section of his report he hypothesized that "if the amount of water increases, then the distance decreases." He then went on to support this hypothesis with the following statement.

> A personal experience was, when I put water in bottle with a lot of air in it, then I stomp on it and the air inside pushed the water out fast. But with more water the water came out slower because there was less force. Also I have launched water rockets before. [S_3, TA, final report]

In the first case he explained the hypothesis by referring to an analogical situation in which he filled a bottle with air and water and forcefully stepped on it. In this case he explicitly connected this to his investigation and hypothesis. In the second case, he referred to prior experiences launching water rockets, but did not attempt to use this to explain his hypothesis.

Systems-based Explanations

Systems-based explanations occurred when students used interactions between different components of the system they were investigating to explain predictions, ability to control variables, observations, and results. These explanations differed from concept-focused explanations in that they relied on specific characteristics of the system they were investigating (i.e. the water rocket) rather than reference to specific scientific concepts.

Although the investigations were designed with one independent variable that they were changing, it was not possible to hold all other variables constant because of the nature of the system they were investigating. This was particularly an issue for students investigating the water question. Changing the amount of water in the rocket before launch also changed the initial weight of the rocket and the volume available for air in the rocket. Although the air pressure was kept constant (i.e. at 30psi), as more water was added, the volume available for air pressure was decreased. This became a key issue as students' results showed an initial increase and then decrease in the distance the rocket traveled as the amount of water was increased to capacity.

Students in three of the groups discussed this when explaining their hypotheses and designing their experiments and two groups discussed this when explaining their results. The following transcript shows a segment of discourse in which the TaGm group discussed how changing the amount of water would affect the room available for air pressure. In this case the students expressed some confusion about how increasing the amount of water would affect the air pressure (line 4), but seemed to have a fairly good grasp of the relationship between increasing the amount of water and decreasing the amount of space available for the air.

TaGm, 10-27-05
1 S: If you were to add more water, wouldn't that have. Wouldn't that mean less air going to it?
2 S: Yes it would.
3 S: It would make less air go inside.
4 S: No, it would just like bust.
5 S: The air, the water takes up the space of the air.

In other cases, students' misconceptions about air pressure seemed to affect their reasoning about the system and their hypotheses about what would happen. TbGmS_3 realized that there was a relationship between the amount of water in the rocket and the air pressure, but he believed that adding more water would compress the air more and result in more force pushing the water out (lines 4-8).

TbGm, 11-1-05

1 S_3: I think if the amount of water increases there put more pressure on the air to get out.
2 S: So it will make it travel farther?
3 S_3: Yeah, I don't know. Yeah, I think it will make it shoot out faster because there will be like more…
4 S_1: Like a faster lift off, but not as far distance?
5 S_3: Because it will compress the air.
6 S_4: No, a faster lift-off and a faster distance, farther distance.
7 …
8 S: I think that the faster it lifts off, the farther it will go, because the air will be more compressed up in like the top so it will want to shoot out even more.

The TbGf group also realized that increasing the water would decrease the room available for air pressure (lines 1-3). Based on this they decided to only fill the 2 liter bottle to a maximum of 1 liter which resulted in their results only showing an increase in distance as the amount of water in the bottle was increased.

TbGf, 11-2-05

1 TB: You can fit, I'll just tell you so you can decide. You can fit 2,000ml in there, so you want to think of a big range.
2 S: Oh, we can do it by 50.
3 S: By 500's, 500, 1,000, 1,500.
4 S: That's a lot.
5 S: Wouldn't it go really far then?
6 S: No, you have no room for air pressure so there will be…
7 S: Oh yeah.
8 S: Good one, uh huh.
9 S: I think we should go by like 150 or 175.

The water rocket inquiry investigations were intended to vary only one variable. However, in some cases reasoning about the results involved not only reasoning about changes in the independent and dependent variable, but also changes in other variables that were affected when the independent variable was changed. For students investigating the water question, this systems-based reasoning was crucial to explaining their results (i.e. that as the amount of water increased, the distance increased and then decreased).

Concept-focused explanations

Concept-focused explanations occurred when students used scientific facts, concepts and ideas to explain predictions and results. These types of explanations occurred when students were explaining and providing supporting evidence for their hypothesis and when attempting to explain their results.

These explanations varied from fairly simple connections between the independent variable they were changing and concepts such as force and mass, to more complex explanations involving concepts such as momentum and Newton's third law. For example, a student from the TbGf group, when probed to explain why she predicted that the distance would increase when the amount of water increased, she replied by simply stating "force" without explaining how force was related to changing the amount of water or the distance the rocket would travel.

> TbGf, 11-2-05
> TB: There's a lot of supporting evidence. You guys think the distance will increase as you increase the amount of water. What makes you think that?
> S: Force.

In other cases students explicitly identified the laws and concepts they were using to explain the results. For example, when the students in the TbGm group were discussing their hypothesis that increasing the amount of water would increase the distance the rocket traveled $T_bG_mS_1$ suggested that Newton's third law could be used to explain it. His statement implies that adding more water increases the action of the water leaving the rocket, which results in an equal reaction propelling the rocket forward. $T_bG_mS_4$ clarifies his statement to explicitly connect the increase in amount of water to a "stronger reaction" resulting in launching the rocket further.

> T_bG_m, 11-1-05
> S_1: For every action there is an equal and opposite reaction. Meaning, when you're adding more water, there's gonna be more water coming out with different forces applied, with the same forces applied propelling it forward.
> S_4: When you add more water a stronger reaction will apply … to launch the rocket further.

Students tended to explain their results in terms of multiple concepts. Figure 14 provides a list of the concepts that students referred to in their explanations during the Student Inquiry. In addition, some students' explanations were taken directly from the classroom notes that they took about Water Rocket Force and Motion.

- Claim – Conservation of Momentum
- First Law (inertia)
- Second Law (F=ma)
- Third Law (action-reaction)
- Relationship between acceleration and mass
- Relationship between momentum and inertia
- Thrust
- Force
- Momentum
- Gravity
- Aerodynamics
- Water Rocket Force and Motion Notes

Figure 14. Concepts employed in concept-focused explanations

In many cases, the concept-focused explanations seemed to originate from students searching their journal notes for possible concepts and then going through a process to determine if the concepts were relevant or not. This process can be characterized as one of "trying on concepts". In many ways this strategy is analogous to the guess and check strategy in mathematics problem solving. Of the four groups this type of discourse was the central focus of group T_bG_f, was present in groups T_bG_m and T_aG_f, and entirely absent in group T_aG_m.

An example of the discourse from T_bG_f will be further discussed to show the nature of this "trying on concepts" strategy. Phrases taken directly from the students' notes are in bold in order to differentiate between what they are taking directly from the notes and how they are using the notes. In this transcript, the students are discussing supporting evidence for their hypothesis that increasing the amount of water in their rocket will result in the rocket traveling a greater distance. The student discourse can be broken into distinct sections in which one student proposes a concept and then students engage in clarification of the concept and/or discussion of its relevance. In this transcript, students discuss Newton's 2nd law, 1st law, momentum, 3rd law, and gravity. In analyzing this transcript, I will start chronologically. Then I will examine themes in the student interactions and structure of the discourse.

The discourse starts with S_3 reading the instructions for providing supporting evidence for the hypothesis.

1 S_2: OK, supporting evidence for hypothesis.
2 S_3: [Reads instructions from handout] Write down information you already know that is relevant to the claim, question and hypothesis. So, ok so.

S_1 then locates a statement from the journal notes (line 3), "the acceleration of an object depends on the mass" and attempts to relate it to changing the amount of water in the rocket. This statement is part of their notes regarding Newton's 2nd Law of Motion.

3 S_1: I think right here, it says **the acceleration of an object depends on the mass** and when you add more water there is more mass added.
4 S3: So what?
5 S1: Right here, **the acceleration of the object depends on the**, oh wait, that's acceleration.
6 [inaudible]

2nd Law

Two things should be noted here. First of all, S_1 only pulls part of the statement regarding Newton's second law from the notes. The full statement is "the acceleration of an object depends on the mass of the object and the amount of force applied". Since this line of reasoning is stopped short in line 5, it is difficult to tell whether Se was ignoring force. However, if the line of reasoning was continued the way it was stated, it could lead to misinterpretations and flawed explanations. Secondly, S_1 stops this line of reasoning because she is questioned by S_3 about how it is relevant (line 3) and when she restates it she seems to question whether or not acceleration is relevant to their hypothesis (line 4). Acceleration can be related to the distance that the rocket travels, but it seems that S_1 does not make this connection and therefore drops this line of reasoning.

In line 7 the conversation turns to a discussion of Newton's first law. S_3 suggests that "an object has more mass, it has more inertia" (line 7). This comes from the students' notes on Newton's first law on page 11 of their journal. Lines 9-26 are then spent figuring out where in the journal this statement occurs and what exactly it says. However, no effort is made to discuss how this relates to their investigation or their hypothesis. Students do not seem to question the relevance of these statements. In line 3, S_1 has already made a link between increasing the amount of water and increasing the mass. So the students may not feel a need to discuss this relationship. However, it is not clear from their previous discourse how increasing the inertia might be related to the distance the rocket would travel. The students do not discuss this connection.

7 S3: **An object has more mass it has more inertia**.

8 S2: Yeah.

9 S1: Where?

10 S3: It's 11.

11 S2: **The first law**.

12 S3: **of motion**.

13 S1: Isn't it?

14 S3: **If an object has more inertia it will take more force to start or stop or change direction of the object.**

15 S1: **Law of inertia**. Oh.

16 S1: **If an object has more inertia it will take more force to start or stop**, no that's not it.

17 S4: No that's **Newton's First Law object stays in motion**.

18 S1: Yeah **if an object has more mass it has more inertia.**

19 S2: It will…

20 S4: What the heck. [Student from another table is throwing stuff at them]

21 S3: OK, so. **If an object has more mass, it has more inertia.**

22 S1: **An object with more mass.**

23 S4: What?

24 S3: No, **if an object has more mass.**

25 S1: **An object with more mass has more inertia.**

26 S3: No, **if an object has mass it has more inertia**. Same thing.

1st Law

In line 28 one of the students probes the group for more concepts. S_2's identification of a concept from the notes initiates a discussion of momentum, "If you get the mass moving in one direction, momentum is transferred in the opposite direction" (line 29). This is part of the description of the Law of Conservation of Momentum from their notes. In lines 30 and 31 other students in the group question how that is relevant and then in line 34, S_1 connects it to Newton's third law of motion which states that "for every action there is an equal and opposite reaction." In the journal notes the Law of Conservation of Momentum and Newton's third law are discussed separately, but on the same page, and the student has made this connection between the two to support her explanation. She then restates her original statement in line 36.

27 S1: And then…
28 S3: Ok, what else?
29 S1: **If you get the mass moving in one direction, momentum is transferred in the opposite direction.**
30 S: What?
31 S2: I'm confused.
32 S4: **Law of conservation of momentum**.
33 S3: What page is that on?
34 S1: **For every action there is an equal and opposite reaction.**
35 S3: What does that have to do with the question?
36 S1**: If you get the mass moving in one direction, momentum is transferred in the opposite direction.**
37 S: How does that relate because the water?
38 S1: Well the waters gonna be pushing out making the rocket go farther.
39 S3: Mass and distance.
40 S2: Yeah that doesn't make sense.
41 S1: Because, like say it's like a pencil right here, like dominos, when the pencil falls over it hits the other one so it makes it move over here.
42 S3: Oooh, the more **inertia**, the more **momentum**.
43 S: …water rocket?
44 S3: The more **inertia** it equals the more **momentum**. **The more momentum an object has the harder it is to stop.**
45 S4: **Mass in motion creates momentum.**
46 S3: What does momentum have to do with any of this?
47 S4: It's going farther, so the airplane has momentum.

Momentum

One of the students still questions how this is relevant to changing the water (line 37). In lines 38 and 41, S_1 tries two additional ways of supporting her explanation. In line 38 she explicitly links the original statement to both the water and distance when she states, “Well the waters gonna be pushing out making the rocket go farther.” S_2 continues to be confused (line 40) so S_1 tries using an analogy to help explain the connection. The analogy she uses is of one pencil falling over and hitting another one.

In lines 42 and 44, S_3 connects momentum to inertia. In the students’ notes, momentum is defined as the amount of inertia. S_3 suggests that “the more inertia the more momentum” and then connects this to another statement in the notes about how “the more momentum an object has the harder it is to stop.” This seems to make sense to her, but then she stops herself and questions what any of it has to do with momentum. S_4 suggests that “mass in motion has momentum” (line 45) and that the airplane (not sure if she is referring to the rocket or an actual airplane here) is going farther, so it has momentum (line 47).

In lines 48-50, Newton’s 3rd and 2nd law are invoked, but not discussed.

48	S2: **For every action there’s an equal and opposite**, uhhh. We have nothing to support it with.	3rd Law
49	S3: Well duhhh.	
50	S: **Where’s Newton’s Second Law?**	2nd Law

In lines 51 and 55 the students once again attempt to connect it back to inertia. They first question whether inertia is like mass and then they restate the statement from Newton’s first law of motion, “If an object has more inertia it will take more force to start, stop or change direction of the object.” This is very similar to the statement from the notes regarding how objects with more momentum are harder to stop. This seems to further support the relationship between inertia and mass, but this is not made explicit.

51	S: Isn’t **inertia** like **mass**?	Inertia
52	S3: Math?	
53	S: Mass!	
54	S3: Math… Safety first.	
55	S2: **If an object has more inertia it will take more force to start, stop or change direction of the object.** Oh, my gosh.	

In lines 56 and 58 S_1 attempts to explain the hypothesis using a fuel analogy. This type of explanation is different than the previous concept-focused explanations as it does not refer to any specific science concept, but rather uses personal experience to explain.

56	S1: The more fuel the faster and longer it lasts. (laughs).	Fuel Analogy
57	S3: If you add more water, it will go farther.	
58	S1: Water equals fuel. Fuel equals longer, longer equals greater distance.	

Finally in line 59, S_2 suggests gravity. S_3 then questions what gravity has to do with it. S_2 states the definition of gravity from their notes and then they jokingly argue back and forth over whether this is relevant or not.

59	S2: OK. Ok, how about this one, **gravity.** (laughs)	Gravity
60	S3: What does gravity have to do with it?	
61	S2: **The force of attraction between objects.**	
62	S: No.	
63	S: It works.	

In summary, student discourse in this transcript consisted of one student proposing a concept taken from classroom notes and then a clarification of the concept and/or discussion of its relevance. In most cases, the initial proposal of the concept was followed by another student questioning the concept. This is seen in statements such as “so what?” (line 4), “What”, “I’m confused” (lines 30 and 31), and “What does gravity have to do with it?” (line 60).

In some cases, this questioning caused the student who proposed the concept to reconsider and drop this possible explanation as in the discussion of Newton’s 2nd Law (lines 3-5). In other cases, the request for clarification resulted in a fairly prolonged discussion of the concept without any discussion of its relevance to the investigation or hypothesis (lines 7-26).

In the case of the discussion regarding momentum (lines 29-47) the requests for clarification led to an extended discussion of the relevance of the concept to the investigation. This section of the discourse included multiple requests for clarification (lines 30, 31, 33, 35, 37, 40, 46). These multiple requests for clarification challenged the students to further explain the connection between the concept and the investigation and to further clarify the concept itself. Initially the requests for clarification resulted in an identification of the law to which the initial statement was related to (line 32), a statement of a similar concept (line 34), and a restatement of the original concept (line 36). Then the request in line 37, specifically asked what this has to do with water. This request challenged S_1 to explicitly link the concept to the investigation (line 38). Following this explanation, S_2 continued to be confused, so S_1 attempted to use an analogical explanation to clarify the concept of conservation of momentum (line 41). In line 46, S_3 still expressed confusion about what momentum "has to do with any of this". So S_4 attempted to clarify by connecting the motion of an airplane to momentum.

In summary, students engaged in the development of concept-focused explanations when providing supporting evidence for their hypotheses and when explaining their results. These explanations were primarily prompted by the teacher's instructions to connect their hypotheses and conclusions to scientific facts, ideas, and concepts. Student discourse related to concept-focused explanations often followed a pattern of concept identification, questioning concept relevance, then either dropping the concept or justifying the concepts relevance to the hypothesis or investigation.

Student Explanations – Linking Evidence and the Claim

To further examine the nature of students' concept-focused explanations, specifically those in which students linked the evidence from their inquiry investigations to the claim, the written reports from all of the students in the 8 study classes were examined. The analysis sections were examined to determine if students were connecting their results to the claim and the nature of the connections that students were making.

Subquestion a: Do students connect their results to the claim?

Examination of the analysis sections of the inquiry reports showed that a majority of the students did not address the claim about the conservation of momentum. 70% of the work samples from Anne's classes and 48% from Brenda's classes did not address the concept of momentum at all in their analysis of the data (Table 16). This was fairly consistent across the four types of questions that students investigated. Hypotheses for this difference will be discussed in chapter 5.

Table 16. Number of students that addressed the claim

Anne's Classes	# Students	Explicit	Implicit	Not addressed
Water Question	76	14%	14%	71%
Mass of Nose	14	29%	14%	57%
Density Question	7	29%	0%	71%
Volume of Rocket	3	0%	0%	100%
Total	100	17%	13%	70%

Brenda's Classes	# Students	Explicit	Implicit	Not addressed
Water Question	74	35%	22%	43%
Mass of Nose	10	20%	0%	80%
Density Question	0	NA	NA	NA
Volume of Rocket	0	NA	NA	NA
Total	84	33%	19%	48%

In some cases it was clear that the students were referring to the claim in the analysis section. These references were coded as explicit references. For example,

> The Conservation of Momentum affects the motion of an object. As the amount of mass increased its distance decreased. The reason the rocket went further with 100 grams of mass is because with no mass it has no momentum but with more mass it has no inertia. [TB5019]

In this case the claim is clearly stated in the students' analysis section. However, in other cases, students mentioned the concept of momentum in their analysis but it was unclear if they were referring to the claim and attempting to connect their results to the claim or whether they were only attempting to use the concept to explain their results. These references were coded as implicit references. For example,

> As the amount of water increased, the distance traveled by the water rocket increased also, therefore, as the force applied to the water rocket increased, its motion also increased. The reason the water rocket went farther with more water is because of Newton's 3rd law of motion. The more action force (water) there is more reaction force (momentum) making the rocket goes farther. [TA5027]

In this case, the term "momentum" is included in the students' analysis section. However, it is not clear that the students are referring to the original claim.

The work samples that implicitly or explicitly addressed the claim were further analyzed to examine the nature of the connections that students made between the evidence and the claim. The work samples fell into four main categories (Table 17). The first category includes work samples in which the claim was stated, but no connection was made between the claim and the investigation. Seven percent of the work samples were of this type. In one case coded in this category, the student explicitly stated that they didn't know how to address the claim or relate it to their results. As this student stated, "I'm not exactly sure why this data corresponds to this claim." [TB4005].

Table 17. Connections between the results and the claim

Nature of the Connection	Type	Examples
No Connection (7%)	a) States the claim/momentum and states that they don't know how to address it. (1)	"Well as you can see by the data as you add more water the rocket goes farther, except for the 1500ml it had so much water in it that it didn't have enough room for air pressure their for it didn't go as far as the other amounts of water. The other rockets had more room for air pressure. **I don't know how to address the claim in a correct statement.**" [TB4005]
	b) States the claim/momentum, but doesn't relate it to the results or the investigation. (4)	"Our conclusion is, **we had a claim that said, The conservation of momentum affects the motion of an object. To prove our claim right and do the investigation we made a question**. How does the amount of water affect the distance a water rocket travels? The amount of water affects the distance a water rocket travels because as you add more water it takes longest to launch into the air." [TB4028]
Results Support Claim, No Explanation Related to the Claim (18%)	a) "Claim" affects results (1)	"The data went up then down. **The conservation of momentum affects the water rocket in a negative way.** It holds back the rocket so it doesn't go as far. It could be positive because we wouldn't want it to go to far." [TA2002]
	b) Results support/relate to claim (12)	"We found that the more water we put in, the further distance it went. But when there was no water it didn't go very far either. The graph I drew, its correlation was positive and then it changed to negative at the end. Also, the rocket went the furthest when it had 1000 mL of water in it. It went the shortest distance when it had 0 mL of water in it. **Our results supported the claim because as we added more water to the rocket, it went further, but then decreased in distance. So it proves that the conservation of momentum affects the motion of an object.**" [TB4026]
Explanation, No connection to results (13%)	a) Explains the concept of conservation of momentum (9)	"The conservation of momentum affects the motion of an object in this experiment **because the momentum is never lost it is transferred which thrusts the rocket into the air.** My evidence supports my claim because it says that momentum affects the motion of an object. If an object has more mass meaning more inertia it is harder to get in motion. Creating a smaller acceleration causing the rocket to travel a smaller distance." [TB5002]
Explanations Attempting to Link Results to the Claim (63%)		"As the amount of water increased the distance increased until we added 1500 ml of water. Therefore, the conservation of momentum affects the motion of an object. The reason the water rocket went far until one point is **because we add more mass and the more mass the more momentum but the rocket couldn't have too much mass or it wouldn't go as far.**" [TB4019]

The second category includes analyses in which the students stated that their results supported the claim, but did not provide any explanation for how the data related to the claim. 18% of the work samples were of this form. For example, one student stated "Our results support our claim because as we added more water to the rocket, it went further, but then decreased in distance. So it proves that the conservation of momentum affects the motion of an object." [TB4026]

The third and fourth categories involve attempts at explaining how momentum is related to their investigations. The third category includes analyses that attempt to explain the concept of momentum or the conservation of momentum and relate it to the rocket, but do not relate this to their actual results. In most cases this involved describing how the conservation of momentum was related to how a water rocket works. For example, "The conservation of momentum affects the motion of an object in this experiment because the momentum is never lost it is transferred which thrusts the rocket into the air. " [TB5002]. 13% of the references to the claim were of this form.

The fourth category includes attempts to not only link the claim and the results, but also to explain the connection between them. A majority of the work samples that referenced the claim attempted to explain this connection (63%). The nature of these explanations will be discussed in the next section.

Subquestion b: What is the nature of the connections that students make between the results and the claim?

In order to identify patterns in student explanations, students' written reports were transcribed and translated into causal representations which highlighted connections which students were making between the inquiry investigation and related science concepts (Appendix L). See the methodology section for more details on how these causal representations were created.

These representations were used to examine the explanations in regards to (a) the connection between the concept of conservation of momentum and water rockets, (b) the relationship between the independent variable (IV), dependent variable (DV), and momentum, and (c) the level of causal complexity of the explanation. The following discussion will examine these three aspects for the inquiry questions related to changing the amount of water in the rocket and the mass of the nose of the rocket.

Water Question

Forty of the students investigating how the amount of water affected the distance the rocket traveled attempted to relate their explanations to the concept of momentum. The following analysis is based on the inquiry reports from these students.

Conservation of Momentum: Distinction between Momentum of the Water and Momentum of the Rocket

Applying the concept of conservation of momentum to the water rocket investigations involves seeing the water rocket as a system in which the momentum of the system is conserved. In this system, the momentum of the water leaving the rocket is equal to the momentum of the rocket being propelled in the opposite direction. However, only 8 of the 40 students made a distinction between the momentum of the water and the momentum of the rocket.

Most of the students discussed how adding more water to the water rocket gave it more momentum. For example, "As the amount of water increased, the distance traveled by the rocket increased until it got to a certain point, then it decreased. Therefore, as the amount of water applied to the water rocket increased, its momentum also increased until it got to a certain point then it decreased." [TB6004] However, they do not discuss this in terms of the conservation of the momentum of the system.

Furthermore, two of the students expressed a common misconception about the transfer of momentum. These students described the momentum being transferred from the water to the ground and then back to the rocket. For example, one student explained that the distance traveled by the rocket decreased as more water was added because, "as more water is added, the less momentum was transferred to the ground and back into the rocket." [TB6023]

Causal Reasoning: Primarily Linear Causal Reasoning

Student explanations were examined to determine what level of causality they exhibited in the interaction pattern dimension. The levels of complexity found in the student explanations for the amount of water question consisted of primarily linear causality with some including mediating factors (See Table 1 for descriptions of these levels). Reasoning about conservation rules, such as in the conservation of momentum, involves constraint-based causality. In constraint-based causality, the behavior of the system reflects a set of constraints that the system obeys. However, the level of causality required to reason about the system depends on the phenomena that the explanation is being applied to (Grotzer and Perkins, 2000). Therefore, the level of causality in student explanations will be discussed with particular reference to the actual results the students were explaining. For the water question, some students had results that showed an increase and then decrease in distance, others only showed an increase or only a decrease.

In the case of the question about the amount of water, it is possible to explain the relationship between the results and the claim using multiple linear causality and invoking mediating factors. In this case, the amount of space available in the rocket for air acts as a mediating factor on the relationship between increasing the amount of water in the rocket and the distance the rocket travels. Most of the students found that as they increased the amount of water in the rocket at launch, the distance the rocket traveled increased to a point and then began to decrease. Figure 15 shows model causal representations for the increase and decrease in distance for the water question. As the amount of water in the rocket increases, the volume available for air pressure decreases. As long as there is enough air pressure to expel the water, then increasing the water in the rocket at launch will result in more water (i.e. mass) leaving the rocket. This increases the momentum of the water leaving the rocket. Based on the conservation of momentum, the momentum of the rocket traveling in the opposite direction would also increase. Since the mass of the rocket cannot be increased, its momentum is increased by increasing its velocity, which increases its distance.

Example A: Model Causal chain for the increase in distance:
More Water → More Mass (w) → More Momentum (w) → More Momentum (r) →
More Velocity (r) → More Distance

Example B: Model Causal chain for the decrease in distance:
More Water → Less Volume (a) → Less Mass (w) → Less Momentum (w) →
Less Momentum (r) → Less Velocity → (r) → Less Distance

or

More Water → Less Volume (a) → Less Mass (w) → More Mass (r) → Less Velocity (r) →
Less Distance

Figure 15: Model Causal Chains for the Amount of Water Question
(w = water leaving rocket, r = rocket, a = air, i.e. Mass (w) = Mass of water leaving rocket)

However, as the amount of water in the rocket continues to increase past about half full, the volume of air pressure in the rocket is not enough to expel all of the water and therefore the amount of water (i.e. mass) leaving the rocket decreases. The relationship between this and the decrease in distance could be explained two ways. First, as the amount of water leaving the rocket decreases, then the momentum of the water leaving the rocket decreases which results in a decrease in the momentum of the rocket moving forward. This results in a decrease in the velocity that the rocket is traveling which results in the rocket traveling a shorter distance. As the amount of water leaving the rocket decreases, more water is staying in the rocket, increasing the mass of the rocket. This would also result in a decrease in the rockets velocity and a decrease in the distance it travels.

Students that only tested values of water from zero to about half full had results that showed only a positive correlation between the amount of water and the distance the rocket traveled. These results can be easily explained using a simple linear causal explanation. Figure 15, Example A, shows an example causal chain that could explain the positive correlation between the amount of water and the distance traveled.

Nine of the student work samples had results that only showed an increase in the distance the rocket traveled. All of the student explanations in this group employed single causal chains like example A. All of these explanations related the increase in water to an increase in momentum and then a resulting increase in distance. However, they varied in the extent to which they made the links between the independent variable, momentum of the water, momentum of the rocket, and the dependent variable explicit. This will be discussed in more detail below.

Three of the students had results that only showed a decrease in the distance. Two of them used linear causal reasoning to explain the relationship between less water escaping the rocket to a decrease in the momentum resulting in a decrease in the distance traveled (TB6027 and TB6023). These explanations were similar to Example B in Figure 15. These students also employed mediating causes to explain the relationship between increasing the water and having less momentum. They suggested that as the mass of the water increased not all of the water could escape and therefore the momentum decreased.

More Water → Less Momentum → ***Less Distance*** [TB6027]
[not a big enough exit hole for all of the water to escape]
More Mass/not enough force → ***Less Distance***

The third student identified a relationship between adding water and changing momentum, but did not describe whether it increased or decreased the momentum or how it related to the decrease in distance (TB5015).

The majority of work samples had results that showed both an increase and then a decrease in the distance that the water rocket traveled. In these cases, simple causal reasoning was no longer sufficient to explain the results. In these cases, students used a number of strategies for explaining the non-linear results (Figure 16). More than half of the students attempted to explain both the increase and the decrease. Of the students who did not, one of them explained the slight decrease in distance in their last trial as a result of error. Five students had recorded data and graphs that showed a clear increase and then decrease in the distance that the rocket traveled. However, their conclusions stated that the distance only increased or decreased. One student concluded that the distance increased then decreased, but only provided an explanation for the increase in distance.

Only explains increase or decrease

- Unexpected result described as an error (1)
- Conclusion describes the pattern as linear (5)
- Conclusion recognizes the increase & decrease, but only the increase is explained (1)

Attempts to explain both the increase and the decrease

- Use momentum to explain increase and alternate theories to explain the decrease (18)
- Explain non-linear results in terms of momentum (3)

Figure 16. Responses to non-linear results (n=28)

Eighteen students explained the increase in terms of momentum, but then employed alternate theories to explain the decrease in distance. Some of the students explained that the decrease was due to less water being pushed out, but did not relate this to a decrease in momentum of the water or the rocket. The rest of the students related the decrease in distance to an increase in mass, a need for more force, or a decrease in acceleration. Two examples of these explanations are shown below.

1. **a) More Water → More Momentum** ***More Distance***
   b) More Water → More Mass/Less Volume (a) *Less Distance*
   [Not enough room for air pressure]
   [TB6004]

2. a) <1,500ml **More Mass → More Momentum → More Acceleration (r)** ***More Distance***
   b) >1,500ml [Until mass gets too great for the force] → *Less Distance*
   [TA2012]

Although a number of the students were able to provide explanations for both the increase and the decrease, only three of the students used the concept of momentum to explain both the increase and the decrease. Two of the three explanations were not able to provide a consistent rational for why increasing the mass increased the momentum in the beginning and decreased the momentum once the rocket was filled more than halfway with water. One of the explanations related having little mass to lower momentum and too much mass also to lower momentum, but did not provide a rational for why this occurred (TA5006). Another explanation suggested that some water provided momentum which resulted in more distance, but that more water resulted in the same momentum, which resulted in less water leaving the rocket, resulting in a slower rocket (TA5008). The third explanation described how more water resulted in more mass and more momentum, but that even more mass resulted in more inertia, which required more force to move the rocket, resulting in less water velocity and therefore less momentum of the water leaving the rocket (TB5029).

Links between the Independent Variable, Dependent Variable, and Momentum

Looking at the links that students make between the independent variable, the dependent variable and momentum allow for a better understanding of how they are relating the evidence to the claim. Relating the independent (IV) and dependent variables (DV) to momentum involves an understanding of how changing the IV and DV relate to changing the mass or velocity of either the water or the rocket. Students varied in the extent to which they made these links explicit (Figure 17).

Independent Variable (amount of water)

- No explanation of the relationship between adding water and changing momentum (40%)
- Identified the relationship between adding water and change in momentum as one of changing **mass** (33%)
- Identified the relationship between adding water and change in momentum as one of changing the **force**, **velocity,** or **acceleration** of the water (30%)

Dependent Variable (distance of rocket)

- No explanation of relationship between changing momentum and changing the distance (92.5%)
- Identified the relationship between changing momentum and change in distance as one of changing the **mass** of the rocket (2.5%)
- Identified the relationship between changing momentum and change in distance as one of changing the **velocity** or **acceleration** of the rocket (5%)

Figure 17. Relationship between IV, DV, and momentum in student explanations (n=40, percentages may add up to more than 100%, because some students identified mass and force, velocity or acceleration)

Sixty percent of the work samples examined in this analysis attempted to identify the relationship between changing the amount of water and a change in momentum. Thirty three percent stated that this relationship had to do with changing mass and 30% stated that it had to do with changing the force or velocity of the water. In the case of those who identified the relationship as having to do with a change in force or velocity, their reasoning for this varied and in some cases was the result of misconceptions about how increasing the water affected the air pressure. For example, some appeared to believe that adding water would compact the air and increase the air pressure pushing the water out.

> “The rocket went further when it had more water in it because water can compress. Therefore, the air was more compacted inside the bottle, so when the force that was keeping it all in was released, it had more force to give it more momentum to make it go further." [TB5020]

In contrast to student explanations for the relationship between the independent variable and momentum, few students explicitly described the relationship between changing the momentum and resulting changes in the distance the rocket traveled. Only 7.5% of the students described how changing the rockets momentum resulted in a change in its distance. Two of the students described how a change in the velocity of the rocket resulted in a change in the distance the rocket traveled and one student described the relationship between momentum and distance traveled as being related to a change in mass.

Explanations for Mass of Nose Question

Five of the students investigating the mass of the nose question attempted to explain the connection between their results and the concept of momentum. The following discussion is based on the inquiry reports from these five students. Explaining the results regarding this question requires more sophisticated reasoning than explaining the results of the water question.

Increasing the mass of the nose cone increases the mass of the rocket. Because the momentum of the water leaving the rocket stays the same, in order for the momentum to be conserved, the velocity of the rocket decreases in order for the momentum of the rocket to stay the same. As the velocity of the rocket decreases the distance the rocket travels decreases.

$$\text{Mass Question} \qquad m_w \cdot v_w = -\uparrow m_r \cdot \downarrow v_r$$

Using the concept of conservation of momentum to reason about the relationship between increasing the mass of the rocket and the distance it travels requires employing constraint-based causality rather than linear causality. In this case, linear causal reasoning is insufficient to explain what should happen when the mass of the nose of the rocket is increased.

To further complicate the development of explanations for this question, the majority of the results that students received showed that the distance the rocket traveled increased and then decreased. This is not consistent with direct reasoning regarding the conservation of momentum. Explaining the initial increase involves considering mediating factors that are changing as the mass of the nose is changed. These include factors such as the center of gravity of the rocket. This was not a concept that the students explored and therefore it should not be expected that they would employ this concept in their explanations. Once again what is of interest in this study is how students relate their results to the concept of conservation of momentum.

Causal Reasoning and Distinction between Momentum of the Water and Momentum of the Rocket

Student explanations for the mass of the nose question consisted primarily of linear causal reasoning. However, as described above, linear causal reasoning is insufficient to accurately relate the results of this investigation to the concept of conservation of momentum. Some of the students simply related the increasing mass of the rocket to an increase in momentum and then an increase (or in one case a decrease) in the distance the rocket traveled. In this case, the students did not distinguish between the momentum of the rocket and the momentum of the water leaving the rocket and appeared to imply that increasing momentum increased (or decreased) distance without considering the conservation of momentum of the system. The reasoning of the other three explanations is difficult to interpret. However, none of these explanations made a distinction between the momentum of the rocket and the momentum of the water leaving the rocket either.

Links between the Independent Variable, Dependent Variable, and Momentum

In the case of the mass question, the relationship between the independent variable (mass of rocket) and momentum is given. However, as discussed above, students did not make a distinction between the momentum of the rocket and the momentum of the water leaving the rocket. In addition, none of the students explicitly identified the relationship between changing the momentum and the distance the rocket traveled (Figure 18). All of the students implied that increasing the momentum would increase or decrease the distance the rocket traveled, but did not explain why. In this case, this is an important distinction because the relationship between changing the momentum of the rocket and the distance it travels is not a simple linear relationship.

Dependent Variable (Distance)

- No explanation of relationship between changing momentum and changing the distance (5)
- Identified the relationship between changing momentum and change in distance as one of changing the **velocity** or **acceleration** of the rocket (0)

Figure 18. Relationship between momentum and the dependent variable for the mass question (n=5)

Summary

Examination of student inquiry reports suggests that students encountered difficulties explaining their results in relationship to the claim. The main issues related to student explanations will be summarized here and possible hypotheses for these results proposed. These hypotheses will then be further examined in the next section.

Overall, few students related their results to the claim or to the concept of momentum. 70% of Anne's students and 48% of Brenda's students did not address the claim or the concepts of momentum in the written analysis of their results. This suggests that either the students did not see this as something they were supposed to do or they could not figure out how to explain their results in relationship to the claim about the conservation of momentum and therefore either failed to explain their results or relied on other concepts to explain their results.

Most of the students who attempted to explain their results failed to make a distinction between the momentum of the water leaving the rocket and the momentum of the rocket moving forward. In the case of the question investigating the amount of water it is possible to develop an explanation that correctly reasons from increasing the amount of water to an increase in the distance the rocket travels without specifying the distinction between the momentum of the water and the momentum of the rocket. It is possible that the students that suggest that the momentum increases are implying that the momentum of the water increases, which increases the momentum of the rocket. However, this was rarely explicit. It is more likely that the students are only relating their results to the concept of momentum in general and not relating their results to the concept of conservation of momentum, considering the water rocket as a system.

For students investigating the question related to changing the mass of the nose, the students cannot correctly relate their results to the conservation of momentum without considering the relationship between the momentum of the water and the momentum of the rocket. Although only six inquiry reports were examined related to this question, the fact that none of them distinguished between the momentum of the water and the momentum of the rocket suggests that students may not have an adequate understanding of the conservation of momentum as it applies in the context of rocket propulsion.

Examination of the form of causal reasoning used in the student explanations showed that students used primarily linear causal reasoning even when linear causal reasoning was not sufficient to explain the relationship between the inquiry results and the conservation of momentum. For the question investigating the mass of the nose, reasoning from the results to the claim requires constraint-based reasoning. However, the students used primarily linear causal reasoning. This could either be due to a lack of understanding of the concept of momentum or to cognitive difficulties with this form of reasoning or both.

When asked to reflect about how the Claims-Evidence inquiry model influenced students analysis of their results in the post-instruction interviews, both teachers felt that more students were able to connect their results to the science concepts than before and that the claim served as a reminder to connect their results to the concept of momentum.

> It's a better job than when it was just, here's a random question, try to figure out what the answer is. I still think its better with that claim. Just, if the kids do bother to address the claim, they can't help but talk about the content. (Anne, Post-instruction interview)

> I think the claim if anything at the very least is a visual trigger or an auditory trigger. When they look at those words that are scientific and they know in their heads that in someway they should be able to connect it… (Brenda, Post-instruction interview)

However, the teachers also recognized that many students were still struggling with connecting their analyses to the claim. Both of the teachers struggled with the cause of this and suggested possible reasons for some students' failure to discuss the claim in their analysis section. Anne wasn't sure whether the problem was due to student motivation, developmental readiness, or clarity of the instructions.

> There's still those kids that don't, even though you tell them to, 'don't forget to address the claim', they still do. So then they miss that step and I don't know why that is. I don't know if that's just laziness or developmental or me not being clear enough. (TA, Post-instruction interview)

Brenda suggested that students who were unsure of the concepts might be intimidated by the requirement to link their explanation to the claim.

> Well I think … for kids who maybe didn't, they were kind of intimidated, they're like 'I don't get it', I don't, you know just kinda shut down. (Brenda, Post-instruction interview)

Anne also identified that one of the challenges for students was the complexity of the analysis that was required to make sense of the results in the Water Rocket Inquiry. She recognized that it was complicated for students, but felt that one of the advantages of this inquiry was the level of engagement that students felt in building and launching the rockets. She stated "it's complicated and there are a lot of variables involved and it's hard to get something that just has a direct correlation, but it's so high interest" (Post-instruction interview). She felt that even though students struggled with the analysis, that the experience was worth continuing to use this activity.

The teachers' responses in the interviews show that they are aware of the challenges that some students are still having in addressing the claim when explaining their results. The teachers' reflections on the possible reasons for student difficulties focused on the students' confusion about the concepts, students' developmental abilities, and motivation. This is consistent with the researchers' analysis of the complexity of applying the concept of momentum to the water rocket investigations and the higher levels of reasoning required to connect the results to the claim.

Assessment of Student Learning

Student learning of disciplinary science concepts during the Water Rocket inquiry was assessed using the Water Rocket Assessment. The data was analyzed for possible class effects using one-way ANOVAs. Paired t-tests were used to examine trends in the differences between the pre-tests and post-tests for the total test and individual questions.

The changes in scores between the pre-test and the post-test were examined for possible class effects. One-way ANOVAs contrasting the eight classes revealed no significant differences among means for the total test score (F = 1.733, df = 115), part I (F = .737, df = 7, 150), or part II (F = 1.155, df = 7, 115). Since there are no significant differences between the classes the following analyses are based on combining the data for all 8 classes.

Paired t-tests on the total score, Part I, Part II, and the individual questions revealed no significant differences between the pre-test and post-test (Table 18). Positive changes from the pre-test to the post-test were found on questions 2, 3, 5, 7, and 8. Negative changes from the pre-test to the post-test were found on questions 1 and 6.

Table 18. Paired t-tests comparing pre-test and post-test scores

Question(s)	Mean Differences	Standard Deviation	t	df	p-value (2-tailed)
Total Score	.14	1.746	.849	115	.397
Part I	-.01	1.000	-.080	157	.937
Part II	.16	1.333	1.353	122	.179
Question 1	-.05	.388	-1.576	170	.117
Question 2	.02	.422	.729	168	.467
Question 3	.02	.543	.428	166	.670
Question 4	-.01	.446	-.174	166	.862
Question 5	.01	.360	.218	162	.828
Question 6	-.01	.785	-.102	154	.919
Question 7	.09	.686	1.573	144	.118
Question 8	.07	.640	1.239	128	.218

The greatest positive changes occurred on questions 7 and 8. These questions were more similar to the water rocket inquiry that the students conducted. Although the differences between the pre-test and post-test were not significant, these results suggest that students made greater gains on these questions than on the multiple choice misconception questions.

CHAPTER 5
DISCUSSION AND LIMITATIONS

Discussion

Introduction

This chapter expands upon the findings in Chapter IV, discusses connections between the findings regarding students' explanations and aspects of instruction, and places these findings within the context of previous research on student learning during inquiry instruction. The following discussion is organized around the four research questions.

In summary, this study found that the Claims-Evidence Inquiry model provides a framework for encouraging student reasoning about science concepts during inquiry by providing supports for the development of explanations. Student reasoning about science concepts during inquiry was found to occur primarily when students developed explanations. The development of explanations provided the link between the processes of inquiry and the learning of science concepts.

Question 1: Aspects of Instruction Related to Students Development of Explanations

What aspects of instruction influence student's engagement with the science concepts and their ability to link claims to evidence?

There are many models of inquiry and various instructional strategies that have been incorporated into inquiry-based instruction. Understanding the relationship between student learning and inquiry-based instruction requires looking carefully at the specific design of the instruction and the ways in which it is implemented by teachers.

A number of recent studies have examined inquiry instruction and curricula that focuses on supporting students in developing explanations. These studies have provided specific prompts for students development of explanations (Coleman, 1998; McNeill et al, 2006) and scaffolds which support students in making the relationship between theory and evidence explicit in students work (Kuhn & Resier, 2005; Sandoval & Resier, 2004).

The Claims-Evidence approach also makes the distinction between evidence and theory explicit by beginning the inquiry with the scientific theory to be tested. Questions are defined which allow for testing the scientific theory (i.e. the claim) in a specific context. The design of investigations then defines the specific nature of the evidence that will be used to test the theory. In this case, the explanations that students develop are explanations for the relationship between the evidence and the original claim. The goals of this part of the study were to examine how teachers implemented the model in order to support students in reasoning about science concepts and developing explanations which link evidence and claims. The Claims-Evidence approach provides the framework for the instruction and examination of the specific strategies used by teachers during implementation highlights specific instructional issues that may support or hinder students' development of explanations within this framework.

Examination of the instruction showed that the Claims-Evidence inquiry model provided students with the opportunity to develop explanations that linked their investigation to science concepts. During the inquiry, students were encouraged to develop explanations and consider how science concepts, especially concepts involving the claim related to their results. In-depth examination of the instruction suggested that a number of factors influenced students' development of explanations during Claims-Evidence inquiry. These included *explicitly encouraging explanations*, clarifying the *connection between the claim and the investigation,* the *presentation of the claim*, the *nature of the claim*, the *development of science concepts*, the *design of the task*, and the *development of inquiry skills*.

Explicitly Encouraging Explanations

During the Forming a Question or Hypothesis stage of the inquiry and the Analyzing and Interpreting Results stage, the teachers explicitly encouraged students to develop explanations. During the Forming a Question or Hypothesis stage this occurred when teachers required students to provide supporting evidence for their hypotheses. The provision of supporting evidence required students to be explicit about the reasoning for their hypotheses and explicitly connect their hypotheses to scientific concepts and personal experiences. During the Analyzing and Interpreting Results section the teachers required the students to describe how the results of the inquiry answered the question they were investigating and to explain their results using scientific concepts. This required students to move from merely stating conclusions to explaining their conclusions in the context of the larger scientific concepts they were investigating. This also provided students with an opportunity to engage in social discourse in their small groups and in large group discussions related to these explanations.

In the large group discussions, which only occurred during the class example, the teachers scaffolded the development of concept-focused explanations by emphasizing the importance of explicitly linking their explanations to the investigation and specific science concepts. During large class discussions, the students were provided the opportunity to share their explanations. The teachers then expanded on these explanations in order to provide examples of how to more explicitly link them to the investigation and science concepts. The teachers guided the students through these connections by asking them simple yes or no questions. However, students were rarely challenged to engage in discourse related to their explanations or discuss the nature of the evidence for their explanations.

A previous study on teacher scaffolding of student explanations found that teachers utilized different strategies for scaffolding students' development of explanations (Rowell and Ebbers, 2004). One of the teachers in the study, Lara, utilized a number of strategies to scaffold students' recognition of what she considered acceptable explanations. The authors identified these strategies as pointing to what is important to know, moving from descriptive to relational explanations, using print resources to model explanations, and constructing written explanations. The other teacher, Hannah, emphasized strategies that scaffolded students' verbal discourse and emphasized the need to gather evidence to support ideas and develop arguments and explanations. The strategies that Hannah utilized included investigating ideas, asking for evidence to support ideas, constructing oral explanations, using print resources to model explanations, and constructing written explanations.

In this study, Anne and Brenda emphasized strategies that were more similar to the ones utilized by Lara in the Rowell and Ebbers (2004) study. These strategies scaffolded explanations by providing models that explicitly linked the explanation to the investigation and to specific scientific concepts. However, these strategies failed to engage students in discourse that challenged the students to justify their explanations or examine the evidential support for their ideas.

Connection between the Claim and the Investigation

Another factor related to the Claims-Evidence Inquiry Model that appeared to influence students' development of explanations involved the presentation of the relationship between the claim and the investigation. If students' explanations are to link the results of their investigation to the claim then students must see the connection between the claim and the investigation. The teachers did this by explicitly connecting the claim to the questions and by explicitly requiring students to address the claim in the analysis. The written instructions which students were given required students to connect both their question and their analysis to the claim. The instructions for the question stated, "write a question related to the above claim that can be answered by gathering data in a scientific investigation". The instructions for the analysis also required students to link both their conclusion and their explanation to the claim.

However, in both the Class Example and the Student Inquiry the teachers provided the students with the question. Since the questions were given to them, the students were not required to reason about the relationship between the claim and the questions. Analysis of the teachers discourse also showed that the teachers varied in the extent to which they made the relationship between the claim and the questions explicit.

Presentation of the Claim

Another factor related to students' development of explanations involved the teachers' epistemological approach to the claim. Analysis of the teachers discourse related to the claim showed that they emphasized three aspects regarding the claim. First, the teachers focused on claims being based on and well supported by evidence. Secondly, the teachers emphasized that the claims were known to be "true". Thirdly, the teachers emphasized that the claim was being used to “frame” their investigation. The way in which the claim is presented has implications for how students see the purpose of the investigation, the link between their results and the claim, and ultimately the nature of the explanations that they develop to link those concepts.

The teachers presentation of the claim as being based on and well supported by evidence supports students in seeing the importance of supporting claims and explanations with evidence. Furthermore, this may encourage students to see the data that they are gathering in the investigation as further evidence that should be connected to the claim. However, the presentation of the claim as true may de-emphasize the importance of gathering evidence to test the validity of the claim. The students may see their task as merely verifying the concept rather than investigating it and truly evaluating the evidence from the investigation in light of the claim. If the claim is known to be true then what is the point of gathering more evidence for it or developing explanations for the results.

The presentation of the claim as a way of “framing” the investigation may also de-emphasize the importance of the relationship between the evidence the students are gathering and the claim. If the purpose of the investigation is to “frame” the investigation then it suggests that the investigation is inherently related to the claim, but not that the investigation or interpretation of results needs to be directly linked to the claim.

Nature of the Claim

The claim that students investigate in Claims-Evidence inquiry sets the stage for the investigations that students will conduct and the nature of the reasoning that will be required to relate the results of the investigation to the claim. In this study the teachers used two different claims during the Water Rocket Inquiry.

Inquiry	**Claims**	**Questions**
Class Example	The amount of *force* affects the *motion* of an object.	How does the amount of *air pressure* affect the *distance* the rocket travels?
Student Inquiry	The *conservation of momentum* affects the *motion* of an object.	1) How does the amount of *water* affect the *distance* the rocket travels?” 2) How does the *mass of the nose* cone affect the *distance* the rocket travels?

The reasoning required to connect the claim to the results of the investigation differed for the two claims. In the Class Example, the independent variable, air pressure, and the dependent variable, distance, can be directly related to the concepts of force and motion in the claim. However, in the Student Inquiry, students were required to relate the independent variables to a more complex concept, the conservation of momentum. In this case, the relationship between the independent variable, dependent variable, and the concept requires a more extended line of reasoning.

Examination of the claims used in this study highlighted the importance of carefully considering the relationship between the claim and the nature of the task that students will carry out to test the claim. When considering the concept to be used for the claim one needs to consider not only the complexity of the concept, but also the complexity of applying the concept to the specific investigation that will be used to gather evidence for it.

Development of Science Concepts

Students' ability to develop explanations related to the claim is likely to be influenced by their understanding of the concept that is the focus of the claim. In this study, the Claims-Evidence inquiry was conducted after a unit of instruction on the related concepts and used primarily as a way for students to apply the concepts they had learned in a new context. Examination of the instruction suggested that the way in which the concept of conservation of momentum was presented in the prior instruction and the way in which the inquiry required students to apply the conservation of momentum differed in some distinct ways. In particular, the prior instruction presented the conservation of momentum primarily in terms of the "transfer" of momentum of colliding objects, whereas reasoning about the rocket required students to consider how momentum was "conserved" in the system.

Second, the presentation of momentum in the prior instruction implied that the amount of momentum an object had was directly proportional to the distance it traveled. For example, in the Ramp of Ramming, more mass was applied to the cart going down the ramp, which resulted in the ball with which it collided traveling a greater distance. In the presentation of this lab, it was implied that increasing mass, increased momentum, which increased the distance. This reasoning is reasonable within the specific context of this lab, even though it ignores certain aspects of the conservation of momentum. However, when reasoning about how adding mass to the rocket will influence the distance it travels, using this same reasoning creates problems. In the case of the water rocket, increasing the mass of the rocket, does not result in an increase in the momentum of the rocket, and would actually result in a decrease in the distance the rocket travels.

Third, a related issue involving the prior instruction around momentum involves the presentation of the conservation of momentum. In the prior instruction, a distinction was not always made between the momentum of the components of the system being examined. In the examples provided in the prior instruction, it was possible to reason about the phenomena without making a distinction between the momentum of the different components of the system. However, reasoning about the results of the water rocket inquiry required differentiating between the momentum of the water and the momentum of the rocket in order to accurately explain the results.

Design of the Task

The specific investigation that students use to gather evidence to test the claim impacts students' ability to generate explanations. Tasks which provide consistent data with distinct enough differences between data points to produce clear patterns provide a base on which students can formulate explanations. If the results are too messy, then it will be difficult for students to explain the results except by suggesting that the results are due to error or variability in the system. The teachers were very aware of this and in their Pre-Instruction Interviews they discussed how they consciously designed tasks and chose questions that could provide students with "good data".

Development of Inquiry Skills

In order for students to develop explanations based on results from inquiry investigations students must be able to collect accurate data and present data in a form that allows for the identification of patterns. The development of students' inquiry skills is important in supporting students in developing explanations during inquiry. In this study, the teachers carefully structured prior experiences for the students in order to support them in developing the necessary skills needed to successfully design an experiment, collect data and analyze results.

Summary

This analysis examined the aspects of instruction during a Claims-Evidence inquiry activity that supported students in relating evidence from inquiry investigations to specific science concepts through the development of explanations. The teachers' explicit encouragement of explanations scaffolded students in developing explanations that linked evidence to scientific concepts and emphasized the importance of justifying explanations with data and logical reasoning.

The development of inquiry skills and scientific concepts are important for providing students with the skills and understandings needed to develop explanations linking inquiry results to scientific concepts. However, the findings in this study showed that preparing students to apply scientific concepts requires not only presenting the concept prior to the inquiry, but also carefully examining the way in which the concept is applied in the prior instruction so that students are able to transfer the concept to the specific context of the inquiry.

Examination of the instruction also highlighted areas specific to the Claims-Evidence inquiry approach that are likely to influence students' ability to construct explanations. First, in Claims-Evidence inquiry it is important that students understand how the evidence that they are collecting in the inquiry investigation is related to testing the original claim. If the teachers provide the inquiry questions without discussing their relationship to the claim, then students may experience difficulties when it comes to relating the evidence from the investigation to the claim during the analysis of results and construction of explanations. Second, the teachers' presentation of the claim as "true" or something to be tested by the inquiry investigations may influence how students see the purpose of the investigation and thereby influence how they see the relationship between the claim and the data they were gathering in the investigation. Presenting a claim as "true" or merely a way of "framing" the investigation may de-emphasize the importance of gathering evidence to test the claim.

Question 2: The Nature of Student Explanations during Claims-Evidence Inquiry

Where in the inquiry cycle do students invoke explanations and what is the nature of those explanations?

This section of the discussion examines the nature of student explanations during Claims-Evidence inquiry. First, students' explanations in written and verbal discourse are discussed in terms of where they occurred during the four stages of the inquiry. Second, three types of explanations invoked by students during the inquiry are described.

When during the Inquiry Cycle did Students Invoke Explanations?

Student discourse related to science concepts occurred during all four stages of the inquiry. However, the majority of the verbal discourse related to science concepts occurred during the Forming a Question or Hypothesis section and the majority of written discourse occurred during both the "Forming a Question or Hypothesis" section and the "Analyzing and Interpreting Results" section.

Occurrence of explanations during inquiry stages (reprinted from Table 15)

Inquiry Stages	**Type of Discourse**	
	Verbal	**Written**
Forming a Question or Hypothesis	Common	Common
Designing an Investigation	Limited	N/A
Collecting and Presenting Data	*Limited	N/A
Analyzing and Interpreting Results	Limited	Common

*Based on field notes of the entire class, not the focus groups.

During the Forming a Question or Hypothesis stage students formed hypothesis and proposed explanations for their predictions. Explanations during this phase of the inquiry were common in both the verbal and the written discourse. Analysis of the verbal discourse of the focus students found that all four groups engaged in discourse related to explanations during this stage of the inquiry. Analysis of the individual inquiry reports also showed that most students incorporated some form of explanation when providing supporting evidence for their hypotheses.

During the Designing an Investigation stage some groups engaged in extended discourse invoking explanations when discussing the design of their rocket and explanations for why one design was better than another. On the other hand, other groups did not invoke explanations at all during this stage. The explanations invoked during this stage of the inquiry related to explaining how variables within the rocket interacted and how aspects of the design of the rocket could influence the distance it traveled. During this stage some students engaged in discourse related to which variables could be controlled and which couldn't, which was a major component of their understanding of the interactions of variables within the water rocket. For students investigating the water question, understanding the interactions became a key component of explaining how increasing the amount of water in the rocket could result in an increase and then a decrease in the distance the rocket traveled. Students' discourse related to the design aspects of the rocket involved discussions of how factors related to the construction of the rocket such as the number of wings, shape of the nose, and surface of the rocket could affect the distance the rocket traveled. During these discussions students made claims about how the different factors would affect the distance the rocket traveled and explained their beliefs by invoking scientific concepts such as aerodynamics and relating their design ideas to analogous objects such as footballs.

During the Collecting and Presenting Data stage, while actually launching rockets, the focus students were not audiotaped, but individual students were observed to invoke explanations for unexpected results when their rockets did not travel the distances they expected.

During the Analyzing and Interpreting Results section few of the students in the focus groups were found to engage in verbal discourse related to explaining the results of their investigation. During the actual rocket launches students began to develop explanations for their results and engaged in some initial discourse related to explaining why the rocket didn't travel as far as they expected. However, when students returned to the classroom, the majority of the discourse in the small groups focused on describing their procedure, calculating averages, and graphing their results. After completing the tasks involved in analyzing their data, only one group engaged in extended discourse related to explaining the results of their investigation. Analysis of the students' inquiry reports showed that the majority of students invoked explanations when analyzing and interpreting results in their final reports, even though explanations were uncommon in the classroom discourse during this stage.

The results of this study showed that student discourse related to explanations occurred during all four stages of the inquiry cycle, but that the majority of the verbal discourse related to explanations occurred during the Forming a Question or Hypothesis stage of the inquiry. These results are somewhat in contrast to prior studies on student discourse during science investigations that found that student discourse in small groups often focused on processes rather than scientific ideas (Bianchini, 1997; Shepardson, 1996; Krajcik et al., 1998; Jimenez-Aleixandre et al., 2000).

However, this study also found that a limited amount of verbal discourse occurred during the Analyzing and Interpreting Results section. This stage of the inquiry is a crucial point for students to develop explanations and connect their results to science concepts and the claim. Multiple factors may have influenced the lack of verbal discourse related to explanations during this stage.

It is possible that students may not have had time to discuss their results during class because of the need to write their procedures, calculate their averages, and graph their results before getting to the section where they wrote their conclusions and explanations. This was one of the factors that appeared to inhibit student discourse related to science concepts in a previous study by Bianchini (1997). For some of the groups this was probably a factor, but for other groups it was evident that they were working on the conclusions and explanations section, but they did not engage in discourse about the reasonableness of their explanations with the group.

Students may have also felt that they were supposed to write their conclusions and results individually since this was an assignment that would be graded individually as an Inquiry Work Sample. Brenda suggested that in previous grades the students had been allowed to work in groups up until the collection of the data, but that after the data collection they were required to work individually.

The blocks of time that students had to work in their groups during the initial stages of the inquiry were also much shorter and more structured than during the final stages of the inquiry. When students started the inquiry, one of their first tasks was to develop hypotheses and provide supporting evidence for the hypotheses. During this stage of the inquiry, all of the students in the group were at the same stage and had a focused goal to discuss. However, after the data was collected, the students had one to two days of time to work on writing their procedures, calculating averages, graphing data, and analyzing their results. Students in the group completed these tasks at different rates and therefore did not all get to the analysis section at the same time. This may have made it more challenging for students to engage in extended discourse related to explaining the results of their investigation if other members of their group were not focused on working on that section at the same time they were. Further considerations should to be made for ways of structuring the final stages of the inquiry to support students in engaging in discourse related to developing explanations for their results.

Types of Explanations Invoked During Inquiry

Analysis of the nature of students written and verbal explanations showed that students invoked three types of explanations (analogical, systems-based, and concept-focused) that involved different types of reasoning about the phenomena. The discussion of this section will first compare the results to other studies that attempted to identify types of explanations used by students, teachers, scientists and adults. Then each type of explanation identified in this study will be discussed further.

Types of Explanations

A few studies on students' generation of explanations and teachers' use of explanations have attempted to categorize the explanations into types. Table 19 summarizes the findings of three such studies. All of these studies identified explanations similar to the systems-based explanations identified in this study. Only Dagher and Cossman's (1992) study on teachers' explanations identified analogical explanations and characterized explanations similar to concept-focused explanations. One difficulty with examining this research lies in the different terminology used in reporting the results for each study. An attempt will be made to summarize the similarities across the studies and between the different terminologies used.

Table 19. Review of studies identifying types of explanations used by students and teachers.

Study	**Subjects of the study**	**Content focus of the study**	**Types of explanations**
Metz (1991)	3-9 year olds	Physics (gears)	Function of object Connections Mechanistic
Rowell & Ebbers (2004)	Elementary students	Biology (bird adaptations)	Descriptive explanation Relational explanation Explanatory model
Dagher & Cossman (1992)	Junior High Science Teachers	Life and Physical Science	Analogical Anthropomorphic Functional Genetic Mechanical Metaphysical Practical Rational Tautological Teleological

The studies conducted by Metz (1991) and Rowell and Ebbers (2004) examined elementary students development of explanations during science lessons. The Metz study categorized the explanations into function of object as explanation, connections as explanation, and mechanistic explanations. Rowell and Ebbers (2004) categorized the explanations into descriptive explanations, relational explanations and explanatory models. Both the function of object classification and descriptive explanation rely on basic description to explain. For example, it flies because it has wings or it turns because it is round.

The connections explanations, identified by Metz, and the relational explanations, described in the Rowell and Ebbers study, involve explanations that identify relationships between objects or between structures and phenomena. In the connections explanations students explain how the gears work by describing the ways in which things are connected. Relational explanations went beyond mere description to identify the relationship between the adaptation and flight (“strong chest muscles that let them fly”).

The third category in both studies, mechanistic explanations and explanatory models, involves explaining how the relationships result in the phenomena. In the mechanistic explanations students explain how the motion is transmitted through components of the system. In the explanatory models students explained how the adaptations were related to flight ("large muscles in their chest which they use to flap, pushing them up").

The Dagher and Cossman (1992) study examined teachers' use of explanations and identified a number of additional explanation types. These included analogical, anthropomorphic, genetic, functional, genetic, mechanical, metaphysical, practical, rational, tautological, and teleological. The functional explanations described by Dagher and Cossman are similar to the relational explanations identified by Rowell and Ebbers. In these explanations the phenomena is explained by relating it to the function of an object or organism. Dagher and Cossman's characterization of mechanical explanations are also similar to the description of mechanistic explanations described by Metz and the explanatory models described by Rowell and Ebbers. However, Dagher and Cossman extend their definition of mechanical explanations to include explanations that utilize scientific principles, laws and unobservable entities.

The systems-based explanations identified in this study are most similar to the connections as explanations (Metz, 1991) and mechanical explanations (Metz, 1991 and Dagher and Cossman, 1992). Systems-based explanations utilized cause-effect relationships of aspects of the system to explain phenomena, such as the distance the rocket would travel. These explanations are also somewhat similar to the relational explanations identified by Rowell and Ebbers. However, the relational explanations described by Rowell and Ebbers only identify relationships between a component of the system and the phenomena, rather than identifying interactions between components of the system.

The two other types of explanations, analogical and concept-focused, identified in this study were not described in either of the above studies that examined students' generation of explanations. However, the study of teachers' explanations did identify similar types of explanations. It is unclear whether the studies by Metz (1991) and Rowell and Ebbers (2004) did not identify analogical explanations in the student discourse or whether they did not characterize students' use of analogy as an explanation. Additional research on students' generation of analogical explanations will be discussed in the next section.

It also interesting to note that neither of the above studies on student discourse identified explanations that utilized scientific concepts or principles. This may be due to the context in which the explanations were examined or the age of the students. In this study, the Claims-Evidence model placed scientific concepts at the forefront of the investigation and encouraged students to explicitly link their explanations to these concepts.

Analogical Explanations

Students in this study invoked analogical explanations when forming their hypotheses for the investigation, justifying ideas for rocket design, and when explaining results. Analogical explanations employed previous experiences as support for explanations of why something happened or would happen. Students utilized analogies from both personal experiences and classroom experiences. The generation of analogical explanations occurred spontaneously and as a result of prompting from the task instructions.

Much of the research on analogies in science education has focused on the presentation of analogies to students, either by teachers or through curriculum materials. Less research has examined students' spontaneous use of analogies when reasoning about scientific ideas. This study adds to a developing research base documenting student-generated analogies during science. Recently, May, Hammer, and Roy (2006) presented a case study that documented the use of spontaneously generated analogies by third grade students when reasoning about possible causes of earthquakes.

The documentation of student discourse throughout all stages of the inquiry in this study allowed for identification of the stages in which students utilized analogies. The results of this analysis are consistent with previous research that shows that students and scientists engage in analogical reasoning when formulating hypotheses, designing experiments, and explaining results. Azmitia and Crowley (2001) found that undergraduate students used analogies to formulate hypotheses, design and evaluate experiments, and explain their findings when engaging in collaborative reasoning about a design task. Dunbar (1999) examined the nature of scientists reasoning in natural settings and found that scientists commonly use analogies when formulating hypotheses, designing experiments, fixing experiments, and explaining results.

Cognitive research on the use of analogies also suggests that the use of analogy may play a role in utilizing prior knowledge in the acquisition of new knowledge. Vosniadou (1989) suggests, "analogical reasoning can act as a mechanism for enriching, modifying, and radically restructuring the knowledge base itself" (p. 434). Analogical explanations may support students in initially conceptualizing the investigation by being able to connect it to more familiar phenomena.

However, other research on the use of analogies in instruction has suggested that analogies can lead to simplified and possibly incorrect application of knowledge (Spiro, et al, 1989). A study of collaborative scientific thinking during a design task found that in some cases, student generated analogies during collaboration hindered progress because numerous analogies were generated and students did not discriminate between those that applied and those that did not apply to the task (Azmitia and Crowley, 2001). This study also found that students generated a number of analogies, not all of which productively mapped onto the phenomena they were investigating. This suggests that care should be taken to acknowledge the relationship between the analogy and the phenomena so that students don't inappropriately apply analogies to situations that could lead to misconceptions rather than a deeper understanding.

Analysis of the instruction showed that the teachers provided explicit supports for students' development of analogical explanations by encouraging them to use personal experiences, both from inside and outside of the classroom, to support their hypotheses. Recognition and explicit discussion of students' analogical explanations may assist students in determining in what ways the analogies match the concept they are investigating and in what ways they do not.

Systems-based Explanations

In this study, students engaged in developing systems-based explanations when explaining hypotheses, designing experiments, and when explaining results. Systems-based explanations relied on descriptions of interactions between different components of the system they were investigating.

When discussing the design of the experiment, students discussed which variables could be controlled and which could not and how changing the independent variable might affect other variables in the system. In some cases, the students reasoning about the interactions of the system influenced the design of their investigation. In the TbGf group, the students recognized the interaction between changing the amount of water and the volume available for air pressure and used this reasoning to limit the range of the independent variable they were testing.

Students' reasoning about the interactions in the system led them, in many cases, to be better able to explain the results that they received in the inquiry investigation. For students investigating the water question, those who recognized the interaction between the amount of water in the bottle and the amount of volume available for air pressure had a better chance of explaining how the distance the rocket traveled could increase and then decrease as more water was added. However, in some cases students' misconceptions about aspects of the system, such as air pressure, influenced their reasoning about this interaction. For example, some students believed that increasing the amount of air in the bottle caused the water to become more compressed and shoot out with more force.

Students were also found to invoke systems-based explanations when reasoning about the design of the investigation. Analysis of the instruction suggested that the teachers supported students in identifying particular components of the system they were investigating, but de-emphasized interactions between the variables. When designing their investigations, students were asked to identify the independent variable, dependent variable, and controlled variables. The discussion of the controlled variables led a number of the students to discuss the interactions between variables, such as the relationship between adding water and changing the volume available for air pressure. However, the design of the task did not explicitly support students in acknowledging these interactions and considering how they might impact the results. The relationship between changing the amount of water and the volume available for air pressure became a key issue for the majority of students who investigated the water question. Although some students were able to invoke this relationship in explaining their results, a number of students were not.

When inquiry investigations involve analysis of systems in which changing one variable may influence more than just the dependent variable of interest, the development of systems-based explanations may be crucial to fully explain the results of the investigation. Supporting students in recognizing the aspects of the system that are interacting as well as the variables that can be controlled may assist students in making sense of their results and correctly applying relevant science concepts. Reasoning about multiple aspects of a system is more cognitively complex than reasoning about a linear relationship between an independent and dependent variable (Grotzer, 2003). Developing this kind of reasoning in students is important, but may require more scaffolding and consideration of students' developmental levels.

Concept-focused Explanations

Concept-focused explanations occurred when students used scientific facts, concepts, and ideas to explain predictions and results. The development of concept-focused explanations requires that students apply the scientific concept to the particular phenomena that they are investigating. Ohlsson (1992) described this process as one of *theory articulation* (terminology adopted from Kuhn, 1970).

> By theory articulation I mean the activity of applying a theory to a particular situation, to decide how, exactly, the theory should be mapped onto that situation, and to derive what the theory implies or says about that situation. To articulate a theory is an important scientific activity. It is necessary both for relating a theory to observations and for practical applications. Although there are several different types of theory articulations, explanation is perhaps the most important. (Ohlsson, 1992, p.182)

Few previous studies have specifically identified these types of explanations in students' collaborative discourse during inquiry. The results of this study document students' engagement in theory articulation and describe the nature of the collaborative discourse that students engaged in when developing these explanations.

When students engaged in developing concept-focused explanations they often used the strategy of “trying on concepts”. When attempting to develop explanations for their predictions or results, students would search their journals for possible concepts that could be used in their explanation. This strategy was very similar to the guess and check method in mathematics. However, it differs from the guess and check method in that students are not merely determining whether the concept is right or wrong or whether it fits or doesn’t fit, but rather must determine in which ways it fits. During this process students attempted to determine how the concept related to the question they were investigating. This involved relating the concept to both the independent and dependent variable of the investigation. Examination of student discourse showed that students generally followed a pattern of concept identification, questioning the relevance of the concept, then either dropping the concept or justifying the concepts relevance to the hypothesis or investigation. Students often varied in the extent to which they followed through these lines of reasoning to fully connect the concepts to the investigations.

Students’ engagement in this form of discourse appeared to be supported by the teachers’ explicit instructions to use concepts when providing supporting evidence for hypotheses and explaining results. Students in this study were found to engage in discourse about the relevance of the concept-focused explanations. However, students did not always directly connect the scientific concepts to their hypotheses or results.

This analysis documents the nature of student reasoning during inquiry investigations and highlights the various types of explanations that students invoke when making sense of phenomena and when justifying ideas to other students. These results provide important insight into the range of ways that students engage in discourse related to explanations during inquiry.

Question 3: Written Explanations Attempting to Link the Results to the Claim

What is the nature of student reasoning when explaining the relationship between the results and the claim?

The development of explanations requires reasoning about and justifying the relationships between evidence and theory. Development of explanations can occur when generating theories from evidence, when choosing between theories, or when applying theories to particular phenomena. Ohlsson (1992) describes the application of a theory to a particular situation as one of "theory articulation". The student-generated explanations in Claims-Evidence inquiry are of this type. When developing explanations during Claims-Evidence inquiry, students apply the "claim" (i.e. the theory) to the specific results from the investigation.

The majority of research on scientific reasoning about explanations has focused on children's ability to generate (Kuhn, Amsel, and O'Loughlin, 1988) and choose between theories (Samarapungavan, 1992). These studies have examined students' ability to coordinate and differentiate between theory and evidence when determining which variables were responsible for causing a result.

The nature of the reasoning required to generate and choose between theories differs from that required to apply theories to particular phenomena. When applying theories to particular situations the theory is known and the evidence is constrained to a specific context. In this case, the reasoning requires an articulation of how the evidence relates to the theory and which aspects of the theory can explain the evidence. Since the theory is provided the reasoning focuses more on identifying the relationships between the theory and the evidence and less on whether or not the evidence supports the theory. Previous research in science education has not specifically examined the cognitive skills required in articulating theories. The examination of student-generated explanations in this study provides insights into the nature of student reasoning during theory articulation, the issues that arise when applying theories to inquiry results, and possible relationships between students' articulation of theories and instruction.

Analysis of student-generated explanations in this study found that overall few students related their results to the claim, students who attempted to connect their results to the claim often struggled to correctly apply the concept of conservation of momentum to all of their results, and students varied in the extent to which they made explicit connections between the scientific concept and the variables in the investigation. Analysis of the instruction that occurred prior to and during the inquiry suggests some possible explanations for these results. The analysis of student explanations also highlighted differences in the reasoning required to connect the results to the claim depending upon the specific question that students investigated.

Failure to Address the Claim When Analyzing Results

The analysis of students written inquiry reports showed that a majority of the students did not address the claim in their analysis of the inquiry results. In addition, there was a fairly distinct difference in the number of students that addressed the claim in the classes of the two teachers. More students in Brenda’s class (52%) addressed the claim than did students in Anne’s class (30%).

Possible explanations for the low number of students that addressed the claim include: (1) students did not recognize that this was something that they were supposed to do, (2) students struggled to understand the connection between the claim and the investigation they were conducting, or (3) the reasoning required to connect the results to the claim was too complicated. Each of these possible explanations is examined and the instruction of the two teachers is discussed to identify possible causes for the difference found in the number of students that addressed the claim between their classes.

One possible explanation is that the students did not recognize that they were supposed to explain their results in relationship to the claim. Analysis of the instruction showed that the instructions that students were given for the inquiry explicitly asked students to “state the conclusion by answering the question and addressing the claim” and “explain how your results/evidence support the claim using scientific concept, facts, and ideas” (Water Rocket Scientific Inquiry Work Sample Handout). The teachers further emphasized these instructions when discussing the inquiry with the students. However, examination of the teachers discourse showed that Brenda spent more time emphasizing the importance of addressing the claim with her students and discussing the link between the claim and the questions than did Anne. Brenda repeatedly emphasized the importance of addressing the claim in the analysis section of the Student Inquiry. These constant reminders may have encouraged more of the students in Brenda's classes to attempt to address the claim when explaining their results.

Another possible explanation for the lack of connection between the results and the claim in the analysis sections of students' inquiry reports could be that students did not fully understand the relationship between the claim and the investigation they conducted. In the Water Rocket Student Inquiry students were provided with a choice of questions that they could investigate related to the claim or they could develop their own question. However, the presentation of these questions did not include any discussion of how they related to the concept of conservation of momentum. The teachers discussed how these questions would provide good data related to the claim, but did not specifically engage students in thinking about how they related to the claim. Examination of the instruction prior to the Water Rocket Student Inquiry suggested that Brenda more explicitly discussed the connection between the claim and the inquiry investigation than did Anne. During the Water Rocket Class Example, Brenda explicitly described the link between the claim and the question they were investigating. During the student inquiry this connection was not made as explicit, but it is possible that the modeling during the Class Example primed students to see the connection between the claim and the question they were investigating and to recognize that this was something they needed to consider.

A third possible explanation for the lack of connection between the claim and the results could be that the reasoning required for explaining the connection was too complicated for students at this level. Examination of the students' inquiry reports suggests that many students struggled to make the connection between the results and the concept of conservation of momentum. Describing how the conservation of momentum can be applied to the flight of a water rocket is fairly straightforward. However, reasoning about how changing one variable related to the water rocket influences the distance the rocket travels in terms of the conservation of momentum can be much more complex. As described previously, the reasoning required can include linear causal reasoning with mediating causes and constraint-based reasoning which are more complex forms of reasoning (Grotzer and Perkins, 2000).

It is possible that all three of these possible explanations had some role in the large numbers of students that failed to address the claim. Further research is needed to examine each of these possible explanations and explore ways of modifying the instruction in order to assist students with making the connection between their inquiry results and the claim.

Applying the Concept of Conservation of Momentum to the Results

Examination of students written inquiry reports found that students often struggled to apply the concept of conservation of momentum in explaining their results. Applying the conservation of momentum to the water rocket requires considering the water rocket as a system in which the momentum is conserved when the momentum of the water leaving the rocket is equal to the momentum of the rocket moving forward. However, in their explanations students often failed to make a distinction between the momentum of the water leaving the rocket and the momentum of the rocket moving forward.

Analysis of the instruction showed that the students had been exposed to the concept of the conservation of momentum prior to conducting the inquiry. In the prior instruction, they had taken class notes, read a section from the textbook, and conducted a lab on the conservation of momentum. However, close examination of the nature of the concept presentation in the prior instruction and the requirements for applying the concept in the context of the inquiry suggest distinct differences that appeared to hinder students' ability to reason about their results and develop fully accurate explanations.

The differences appeared to result from the simplification of the concept during the prior instruction that may have led to difficulties in applying the concept to a more complex context in the inquiry. For example, in the prior instruction the concept of the conservation of momentum was discussed primarily in terms of the transfer of momentum from one object to another rather than the conservation of momentum of the system. In contexts in which one object is colliding with another, this description of the conservation of momentum is sufficient. However, in the water rocket it is not straightforward to think about a direct “transfer” of momentum from the water to the rocket since they aren’t actually colliding with each other and they are moving in opposite directions.

Also in the prior instruction the relationship between the momentum of an object and the distance it traveled was discussed as a direct relationship without invoking the relationship to velocity. The way this was presented implied that objects with more momentum travel a farther distance. If the mass of the object being observed does not change, then this relationship is reasonable. However, if the mass does change, such as when adding mass to the nose of the rocket, then this relationship is no longer valid.

Finally, in the prior instruction, a distinction was not always made between the momentum of the components of the system being examined. In the lab, Ramp of Ramming, only the ball that was hit in the collision was discussed as having momentum and in the Water Rocket Force and Motion Class Notes only the water was discussed as having momentum. Although the teachers attempted to clarify this during discussion, the majority of the presentation of momentum did not discuss the relationship between the momentum of the components of the system being investigated. Reasoning about the results in the water rocket inquiry required reasoning about the relationship between the momentum of the water leaving the rocket and the momentum of the rocket moving forward.

The simplification of the presentation of the conservation of momentum in the prior instruction resulted in using primarily linear causal reasoning when applying the concept to particular situations. As a result, students were not prepared to use systems-based reasoning when applying the concept of conservation of momentum to the results of the water rocket investigation.

Describing the Relationship between the Concept and the Independent and Dependent Variables in the Investigation

Reasoning about the results of the Water Rocket Inquiry requires that students identify the relationship between the concept of momentum and the independent and dependent variables. Students varied in the extent to which they explicitly connected the concept of conservation of momentum to the independent and dependent variable of the investigation. The majority of students attempted to connect the change in the independent variable (amount of water in the rocket) to the concept of momentum, but very few students attempted to connect the change in the dependent variable (distance the rocket traveled) to momentum.

Analysis of the instruction showed that the teachers provided extensive modeling during large group discussions of explanations that clearly linked the scientific concepts to the independent and dependent variables in the investigation. In these discussions, the teachers probed students to elaborate on their explanations in order to more explicitly connect the scientific concepts to the independent and dependent variables of the investigation. This instruction appeared to support students in recognizing this as a key component of their explanations.

However, students were much more likely to make this connection explicit in regards to the independent variable than the dependent variable. Examination of the prior instruction related to momentum suggests an explanation for this. In the prior instruction the teachers provided students with experiences that modeled the relationship between momentum and changing mass and velocity in the Ramp of Ramming Lab. However, in this lab the relationship between momentum and the distance an object traveled was not explicitly discussed. The distance the ball traveled was used as an indicator of momentum without explicitly discussing the relationship between momentum and distance traveled. Since the relationship between momentum and distance traveled was implied as a direct relationship in the prior instruction, students may not have felt a need to explain this connection in the analysis of their results or they may not have understood this relationship and therefore not been able to explain it.

Causal Reasoning

In the Water Rocket inquiry all of the students were investigating the same claim. However, the causal reasoning required to explain the results in terms of the claim varied depending upon the question that was being investigated and the data that was actually collected. The reasoning required to connect the results and the claim ranged from simple linear causal reasoning to constraint-based reasoning.

Students who investigated the water question and collected data which only showed an increase or a decrease in the distance the rocket traveled could use simple linear causal reasoning to explain their results in terms of the conservation of momentum. Students who investigated the water question and collected data which showed an initial increase and then a decrease in the distance the rocket traveled were required to incorporate mediating causes and multiple lines of causal reasoning. Finally, for students who investigated the mass question, accurately reasoning about the relationship between changing the mass of the nose and the distance the rocket traveled using the concept of conservation of momentum required constraint-based reasoning. Constraint-based reasoning is a more cognitively complex form of reasoning than simple linear reasoning (Grotzer and Perkins, 2000).

The reasoning required to explain the results of the inquiry investigations in terms of the conservation of momentum ranged from simple linear causal reasoning to constraint-based reasoning. However, examination of students reasoning in the written explanations found that students used primarily linear causal reasoning when explaining their results. In cases where the inquiry results were non-linear, multiple lines of causal reasoning or mediating causes were invoked to explain the nonlinearity. Students' use of mediating causes showed an awareness of the complexity of the system they were working with and the interactions among variables of the system.

Although most students were able to provide explanations for non-linear results, few students attempted to explain both the increase and decrease in terms of momentum. Most students explained the increase according to momentum and the decrease using an alternative explanation. It is possible that students did not feel that it was necessary to explain both the increase and the decrease in terms of momentum. This may be due to a difference in how students see the purpose of explanations versus how a scientist would see the purpose of the explanation. A scientific explanation should be able to deduce the phenomena from the general laws or theories and all of the aspects of that phenomenon should be consistent with the general theories or laws employed in the explanation. However, students may not see the necessity of this consistency. To them it may seem sufficient to employ one "law" for part of the results and another "law" for the other part of the results.

For the question related to the mass of the nose, linear causal reasoning is not sufficient to reason from the results to the claim. In this case constraint-based reasoning is required. However, student explanations for this question also used primarily linear causal reasoning.

Question 4: Assessment of Student Learning

What changes occur in student understanding of science concepts as a result of engagement in Claims-Evidence inquiry lessons?

In addition to documenting the nature of student reasoning during inquiry and its relationship to instruction, this study also attempted to document changes in student understanding of science concepts using a researcher developed instrument. The assessment instrument used in this study did not document any significant changes in students' scores between the pre-test and post-test. In order to understand these results it is important to examine the various possible explanations. These negative results have many possible interpretations. One possibility is that the instruction had no impact. Another possibility is that the design of the assessment instrument did not capture changes in understanding that did occur. Both of these possible explanations will be discussed.

In order to understand whether or not the design of the assessment instrument was sufficient to capture the nature of student learning that was occurring during the inquiry, it is necessary to examine the nature of the knowledge that the items assessed, the alignment between concepts in the instruction and concepts in the instrument, the nature of the application of those concepts, and the ability of the questions to elicit the desired knowledge and understandings.

The assessment instrument was designed to assess the concepts related to force and motion identified by the teachers as being present in the inquiry task and to provide a balance of questions between conceptual questions and application questions. A review of the literature failed to identify any previously published assessment instruments that could be used in full form for this study. However, the Force Concept Inventory

(Hestenes et al., 1992) does include some questions that address the identified topics and are written at a level that can be used with 8th graders. Part I of the assessment instrument used in this study consisted of a selection of questions from the Force Concept Inventory used to address the force and motion concepts. Part II consisted of additional open-ended questions developed by the researcher to address application of the concepts to water rockets.

One important thing to note is that the questions from the Force Concept Inventory are specifically designed to assess students' misconceptions. Although it is important for instruction to attempt to address these misconceptions, previous research has shown that students' misconceptions are often strongly held and resistant to change (Wandersee et al., 1994). The instruction in the water rockets inquiry was not focused on addressing specific misconceptions, but rather on increasing students' general understanding of the identified science concepts. It is possible that students gained an improved understanding of the general concepts of Newton's laws and momentum and still held the common misconceptions assessed in these items. Further research is needed to tease apart students general understanding of these concepts from their understandings of related misconceptions.

Examination of the alignment between the test and the focus of the inquiry suggest a slight misalignment concerning the concepts covered. When the test was designed for this study the teachers described the concepts that would be covered in the inquiry as including Newton's 2nd law, 3rd law, gravity, and momentum. Items from the Force Concept Inventory were selected based on these concepts and an examination of the relevance of the questions to the specific application of these concepts in the water rocket inquiry.

The Force Concept Inventory does not consist of any questions related to momentum and the questions related to Newton's 2nd law are not applicable to the way in which students were applying the concept in the water rocket inquiry. Students' application of Newton's 2nd law in the inquiry consisted of reasoning about the relationships between force, mass, and acceleration. The questions in the Force Concept Inventory related to Newton's 2nd law consisted of understanding that a constant force implies a constant acceleration and vector addition of forces. Based on this, the questions selected from the Force Concept Inventory consisted primarily of questions related to Newton's 3rd law and gravity. Questions related to Newton's 2nd law and momentum were not well represented on this part of the assessment instrument. The questions in part II of the test could have been explained using the conservation of momentum or Newton's 2nd law, however, the questions did not require students to do this. Therefore, this analysis suggests that these concepts were not sufficiently assessed on this test.

For the questions from the FCI related to Newton's 3rd law and gravity that were included in the assessment it is important to look at the nature of the application of the concept in the questions compared to the way in which students reasoned about the concepts in the inquiry. For example, in the water rocket inquiry students used Newton's 3rd law to reason about how increasing the amount of force (i.e. air pressure or water) created more action that resulted in more reaction moving the rocket in the opposite direction. Questions 2 and 4 from the Force Concept Inventory also dealt with Newton's third law. However, these questions require students to recognize that objects with different masses exert equal forces on each other. This is a very different application of Newton's third law than the way in which the students were applying it in the water rocket inquiry. Therefore, it is not surprising that students' engagement in the water rocket inquiry did not increase their success on these questions.

Questions 1, 3, and 5 assessed common misconceptions related to gravity. Gravity is related to understanding the flight of the water rocket. However, the inquiry investigations that students conducted did not directly address issues related to gravity or the specific misconceptions related to gravity that were assessed on questions 1, 3, and 5. Question 1 assessed whether students believe that gravity acts differently on objects of different weights. The only situation in which the students were investigating objects of different weights occurred in the groups that investigated how the weight of the rocket affected the distance that the rocket traveled. In this case adding mass to the nose of the rocket generally resulted in an increase and then a decrease in the distance the rocket traveled. Understanding these results requires consideration of additional factors such as the affect of adding mass to the nose on the center of gravity of the rocket and the effect of adding mass to the acceleration of the rocket at lift off.

Question 3 assessed students understanding of the relationship between gravitational forces and passive forces such as the force a table acts upon a book that is sitting on it. There is no related context in the water rocket inquiry that would address this concept. Question 5 assesses students understanding of the forces acting on a tennis ball in flight, particularly the misconception about the force of the "hit" on the ball once it is in the air. The inquiry investigations that the students conducted did not engage the students in reasoning specifically about the different forces that were acting on the rocket at take-off versus during flight. In addition, the water rocket is more complicated than the tennis ball example in that the air pressure and water leaving the rocket continue to provide force moving the rocket forward for a certain period of time during the beginning of the rockets flight. Although students may have reasoned about concepts related to Newton's 3rd law, gravity, and forces during the water rocket inquiry the nature of the reasoning was far removed from the nature of the reasoning required to correctly answer the questions in part 1 of the test used in this study.

The short answer questions in part II of the test were more directly related to the actual inquiry investigations that students conducted. However, examination of the questions suggests that they may not have been specific enough to elicit the understanding of the concepts that was desired. The questions in part II required students to explain how the rocket takes off, how changing the amount of water would affect the distance the rocket traveled, and how changing the mass of the rocket would affect the distance it traveled. The open-ended nature of the questions resulted in a wide variety of student responses and a wide range in the specificity of the explanations. For example, in question 6 some students explained that the water rocket took off by pulling the string. Other students explained the take-off by referring to Newton's third law or the conservation of momentum. The wording of the question did not imply how specific the students needed to be in explaining this concept. Students may have developed a greater understanding of the concept after the inquiry, but not felt that the question required a more specific explanation.

Questions 7 and 8 were also not specific enough and appeared to confuse some students. The questions asked students to explain how increasing the amount of water in the rocket and the mass on the rocket would affect the lift-off of the rocket and the distance the rocket traveled. The students had trouble differentiating between the lift-off of the rocket and the distance it would travel. This distinction is not really important in terms of assessing the concept. So part (a) and (b) of these questions were combined when scoring them. Students' responses to the water question primarily explained how adding water would cause an increase or a decrease. Few responses explained the non-linear results that students found in the actual inquiry. It is possible that the way the question was worded led them to feel that they only needed one explanation.

Questions 7 and 8 could be improved by rewriting them to show bottles filled with different amounts of water or with different amounts of weight. The question could then ask the students to draw a graph showing how the distance would change with the different amounts of water or the different masses and to explain the results using scientific concepts. This would focus students on describing and explaining the full range of results and lead them to using scientific concepts in their explanations.

Analysis of the assessment instrument used in this part of the study suggests limitations of the instrument for assessing the specific concepts and the specific application of these concepts that was prevalent in the inquiry. This analysis suggests that the lack of significant difference between the pre-tests and post-tests in this study may likely have been due to the misalignment of the instrument with the instruction rather than a lack of influence of the instruction on student learning.

However, at this point the possibility that the instruction had no influence on student understanding cannot be ruled out. In this study, the assessment instrument was only administered to classrooms using the Claims-Evidence Approach. Future studies involving comparison classes, using another inquiry approach or a more traditional approach, would help determine if the negative results on the assessment instrument were due to the instruction or a lack of alignment with the test.

Implications for Future Research and Professional Development

The results of this study have implications for future research and professional development related to inquiry in general and the Claims-Evidence model in particular.

This study suggests that the development of explanations provides an important link between the processes of inquiry and the learning of science concepts. Supporting students in developing explanations during inquiry can assist them in making sense of their results and using the results to build a stronger conceptual structure related to specific science concepts.

Implications for Future Research

When reasoning during inquiry in this study, students invoked various types of explanations that relied on different types of evidence and different forms of reasoning. Awareness of the types of explanations that students engage in during inquiry can help teachers and curriculum designers in planning for and assisting students with this important component of reasoning during inquiry. More research is needed on the types of reasoning that students engage in when forming explanations during inquiry.

Research on analogies has shown that the use of analogies can help support learners in bridging their pre-existing knowledge with new knowledge (Vosniadou, 1989). However, little research has examined the nature of student-generated analogies and their influence on student sense-making during inquiry. May, Hammer, and Roy (2006) provide evidence that students as early as third grade engage in the use of analogies when reasoning about scientific explanations. They acknowledge that little research has been conducted in this area and argue that educators “should pay these abilities direct instructional attention” (p. 317). More research is needed to examine when students spontaneously generate analogies, how students determine the adequacy of the analogies, how instruction could support discourse related to student-generated analogies, and how students’ analogical reasoning during inquiry is related to knowledge construction.

The development of explanations during inquiry provides students with an opportunity to reason about the relationship between the results of the inquiry and the related scientific concepts. However, it is still unclear what specific effect this reasoning has on students’ conceptions of scientific concepts. Assessing student understanding of specific concepts and linking it to specific inquiry experiences is a challenging task. The assessments of content knowledge in this study did not show any significant differences in student learning from the pre-test to the post-test. However, challenges with accurately aligning the assessment to the task, developing sufficiently specific probes, and classroom test administration issues may have influenced the inability to document changes in student learning.

Some researchers have also argued that the realignment in students' conceptual structures as a result of inquiry experiences may actually continue to develop weeks after the actual experience. Tolmie et al. (1993) used immediate and delayed post-tests in their studies of elementary students' collaborations during science investigations and found that conceptual development was greater in the delayed test than the immediate test. This suggests that additional research is needed to examine student conceptual development over time following inquiry instruction. Assessments that only examine student learning immediately following the inquiry may underestimate the role of the inquiry experience on students' knowledge construction.

Implications for Professional Development

This study highlighted the importance of encouraging and supporting students' development of explanations during inquiry. The teachers provided explicit instructions for students to develop explanations during the hypothesis generation and analysis sections. These strategies encouraged students to engage in discourse with other students about their reasoning related to the inquiry and specific science concepts. Future professional development on inquiry and the Claims-Evidence model should emphasize ways of encouraging students' development of explanations when generating hypotheses and when analyzing results.

In addition to providing explicit instructions encouraging explanations, this study also highlighted the importance of carefully structuring small group work time and modeling argumentation practices. Examination of small group discourse in this study showed that students engaged in more verbal discourse related to explanations when generating hypotheses than when discussing results. This suggests that students may need more specific supports to focus their discourse during the "Analyzing and Interpreting Results" section in order to encourage students to engage in the sort of discourse about explanations for results that was seen when students were discussing hypotheses. The IDEAS project on argumentation emphasizes the importance of providing structured time for small group discourse in order to support students' engagement in argumentation (Osborne, Erduran, and Simon, 2004b).

Examination of teachers' discourse related to explanations showed that the teachers provided supportive modeling of how to structure explanations that linked science concepts to specific aspects of the inquiry. However, the teachers' discourse did not engage students in examining the adequacy of various explanations or the nature of the evidence used to support the explanations. This suggests that teachers may benefit from additional professional development on ways of supporting argumentation in which students examine the nature of evidence, justify explanations, and critique explanations.

This study also provides implications for future professional development and curriculum development specifically related to the Claims-Evidence Inquiry model. This study highlighted issues related to the Claims-Evidence Inquiry model including the nature of the claim, the presentation of the claim, the relationship between the claim and the investigation, and the importance of considering the nature of the causal reasoning required to connect claims to evidence.

Interviews with the teachers in this study suggested that the teachers struggled to choose a claim that guided students towards concepts to use in their explanations while still leaving them open-ended enough that they didn't give away the answer. Previous professional development on the Claims-Evidence Inquiry model has focused on providing teachers with ways of identifying claims. For example, teachers are encouraged to examine teaching standards and textbooks to identify important scientific concepts that could be used as the claim. However, not all scientific claims may provide productive fodder for student inquiry investigations. More research is needed on the characteristics that make a good claim for use in Claims-Evidence inquiry.

The Claims-Evidence model provides a framework for inquiry instruction that highlights relationships between claims and evidence and supports students in connecting their inquiry investigations to specific science concepts. However, the presentation of the claim may influence students' perceptions of the purpose of the investigation and the relationship between the claim and the evidence they are gathering. In this study, the teachers presented the claim that the students were investigating as a "true" claim. The presentation of the claim in this way may lead students to feel that they are merely verifying a known concept rather than having to examine the relationship between the evidence and the claim in order to determine whether the evidence from a particular context supports the claim and if not, why not. Allowing students to truly question scientific concepts that we want them to learn may be a scary proposition for teachers. Teachers may be wary of presenting the claim as something that could or could not be true and having students find evidence in their investigations which do not support the concept.

When providing professional development for teachers on argumentation, Osborne, Erduran, and Simon (2004) found that teachers were initially concerned that students would be confused by examining alternatives to scientifically accepted explanations. However, the teachers found that providing students the opportunity to discuss and debate how the evidence did or did not support the various explanations made examining the scientifically accepted explanations easier.

Presenting the claim as “true” may also lead students to misconceptions about the nature of science. Although the teachers in this study discussed how scientific knowledge was tentative when specifically discussing the nature of science, the presentation of the claim as “true” may suggest to students that some knowledge is “proven”. The Claims-Evidence Inquiry model provides a framework for examining the nature of evidence and its relationship to claims. However, if the claim is presented as “true” then examining the nature of the evidence becomes pointless and the inquiry turns into a process of merely verifying the concept.

The relationship between the claim and the investigation (i.e. the nature of the evidence that is gathered to test the claim) is another important aspect of examining the nature of the evidence and its relationship to the claim. In the Claims-Evidence tasks investigated in this study the students were generally provided with the questions that they would use to investigate the claim. The nature of the questions limited the types of evidence that would be gathered to test the claim and therefore students were not involved in determining what would count as evidence to support or refute the claim. Examining the nature of evidence used to test claims is an important component of understanding the nature of scientific inquiry (Martin, 1972). Future research on the

Claims-Evidence model should examine how teachers engage students in examining the nature of the evidence used to test the claims. If teachers are not incorporating this aspect into Claims-Evidence lessons then the reasons for this should be further examined in order to modify future professional development to address these issues.

Professional development on the Claims-Evidence inquiry model may need to provide explicit supports for assisting students in examining the nature of evidence. Michael Martin (1972) provides criteria for examining the evidential support of a hypothesis. The four factors he describes include (1) the amount of evidence, (2) the variety of evidence, (3) the precision of evidence, (4) indirect theoretical support. A framework such as this may assist teachers in engaging students in discourse about the nature of the evidence that they are using to support or refute the claim.

This study also highlighted the importance of carefully examining the relationship between the claim and the questions that students are investigating when designing inquiry instruction using the Claims-Evidence model. Examination of student explanations in this study showed that the reasoning required for developing explanations that related the inquiry results to the claim depended upon the specific questions that were being asked and the data that was collected. The causal reasoning that was required to develop explanations in the inquiry was a result of not just the claim or the results but the relationship between the two. If the relationship between the claim and the results that students gather involves higher levels of causal reasoning (Grotzer, 2003), then consideration should be taken as to the developmental levels of the students and the supports that are provided for developing additional models of causal reasoning. Although development can influence students' causal reasoning, curriculum that focuses on developing students understanding of various causal models has helped improve their reasoning and understanding of science concepts (Grotzer & Basca, 2004).

In addition, planning for claims-evidence inquiry lessons should include careful consideration of the relationship between the types of evidence students will be able to gather from the task and the concepts involved in the claim. Consideration of this relationship requires understanding the nature of the causal reasoning that is required to connect the results to the claim and the nature of the transfer between the prior concept development and the way the concept is applied in the inquiry.

Limitations

This study involved a case study of two teachers using the Claims-Evidence Inquiry model. The case within case study approach allowed for an in-depth examination of students development of explanations during inquiry at various levels: at the level of instruction, at the level of small group discourse, and at the individual level as examined in student test scores and inquiry reports.

However, this approach is limited in that it only examined 8 classes in one school. The school examined in this study is in a suburban area and is not very economically or racially diverse. Furthermore, the selection of focus groups consisted of "average ability" students. Care should be taken in generalizing these results to other populations of students.

Another limitation of this study results from all of the data analysis being conducted by one researcher. It is unavoidable that some aspects of the researchers experience, beliefs, and biases could influence the interpretation of results. In the qualitative components of this study, the researcher is the primary instrument of analysis. In this research, data analysis involves the interpretation and narrowing of data in order to identify important patterns. An attempt was made to be explicit about the methods and analytic frameworks used to narrow and interpret the raw data in this study. When analyzing the pre- and post-tests an effort was made to limit the researchers' bias when scoring the open-ended sections of the tests by blinding the researcher to identifying information about where the tests came from or when they were taken. This was done so that the researcher could not unintentionally score the pre-tests different than the post-tests.

Challenges with conducting educational research in real classrooms also influenced the use of the data related to the content assessments. The test data from only about half of the students in the classes was used in the analysis due to a low return rate of consent forms and a high number of incomplete tests. Interpretations of the content assessments are also limited because there was no comparison between classes using the Claims-Evidence approach and classes not using it.

Another limitation related to the content assessments involved the actual design of the test. As discussed above, the test was not perfectly aligned to the actual inquiry that the students conducted. Although similar concepts were addressed in the inquiry, the way those concepts were applied in part I of the test was very different. In part II of the test the concepts and the application of the concepts was better aligned, but the questions may not have been sufficiently specific to capture changes in student knowledge. The test also consisted of a limited number of items.

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APPENDICES

Appendix A

2002 - 2006 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 clearly enough to imply an appropriate investigative design.	A) Proposes precise, safe and ethical procedure that demonstrates application of relevant scientific principles and procedures. N) 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, safe, 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, safe, 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 unclear 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 cannot 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 cannot 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**

[A= Application of Scientific Knowledge N= Nature of Scientific Inquiry C= Communication]

2002 - 2006 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. N) Provides evidence that design, procedures, and results have been reviewed to identify some important limitations and sources of error. C) Explicitly analyzes the results of the investigation to support conclusions that address the question or hypothesis and any relationships discovered.	**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 and 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) Chooses 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 to 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**

[A= Application of Scientific Knowledge N= Nature of Scientific Inquiry C= Communication]

Appendix B: Teacher Pre-Instruction Interview Questions

Teacher's educational background

1. Describe your educational background (i.e. undergraduate, graduate degrees).
2. Describe your science background (courses, work experience).
3. Describe any professional development that you have received related to inquiry teaching.

Teacher's beliefs about inquiry teaching

1. Describe what you see as the important aspects of inquiry-based instruction.
2. Describe how you see the teacher's role in inquiry teaching.
3. Describe how you see the student's role in inquiry teaching.
4. What do you see as the benefits of inquiry teaching for students?
5. What do you see as the challenging aspects of inquiry teaching for students?

Background about teacher's understanding of the C-E model.

6. How have you learned about the Claims-Evidence Inquiry approach?
7. What do you consider to be the key components of the Claims-Evidence Inquiry Approach?
    a. What are the key factors you consider when designing a Claims-Evidence Activity?
    b. How do you determine the Claim to use for the activity?
8. Based on your experience with Claims-Evidence, how does this approach influence student understanding of science content and inquiry?
    a. What aspects of inquiry?
    b. What specific aspects or components of Claims-Evidence influence that?
9. Describe how Claims-Evidence is different from the types of inquiry teaching you did in the past (in terms of its use and influence on student learning).
    a. What are the advantages &/or additional challenges to using this model?
10. What do you hope you will get from this study that will better inform your teaching? (anything specific to the use of Claims-Evidence?)

Teachers' use of Claims-Evidence in the classroom

11. Is this an inquiry activity which you have used before? For how many years?
12. How have you been involved in the development of this inquiry activity?
    a. Was this modified from a previous activity you have used?
    b. How has the Claims-Evidence Activity been modified over time as you have used it?
    c. How did you decide on this claim?
13. How does this Claims-Evidence task fit into the instructional sequence for this unit? Does it come at the beginning or end? Does it come before or after other instruction on these topics?
14. What types of instruction proceeded or will follow this task?

Role of instructional goals on the implementation of inquiry teaching

15. What are your instructional goals for this inquiry lesson (content, process, and other)?
16. How does this task allow students to gather evidence related to the claim?
17. How does that relate to the concepts you want them to develop?

Appendix C: Teacher Post-Instruction Interview Questions

1. In general describe how you thought the water rockets inquiry went this year.
2. How do you feel that it met your instructional goals in terms of students gaining a better understanding of the science concepts they were learning?
3. During what components of the water rockets inquiry do you feel that students had the opportunity to engage in constructing deeper understandings of these concepts?
    a. How did these components provide students the opportunity to engage in constructing these understandings?
    b. What role does classroom discourse play in assisting students in constructing these understandings?
4. In your interview prior to the start of the water rocket inquiry I asked you how you thought the Claims-Evidence Approach influenced student understanding of science content and you made the following statement: (see quote below)
    a. Do you still agree with that statement?
    b. Do you feel that students were able to make that link between the claim and their conclusions in the water rocket inquiry?
    c. What do you think supported or hindered students ability to make the link between the claim and their conclusions?
5. Take a look at the Essential Features of Classroom Inquiry (see below).
    a. For each of the essential features could you describe how the water rockets inquiry addressed these aspects of inquiry?
6. What would you change if you taught the water rocket inquiry again?

<u>Quote from Anne's Interview 10-07-05</u>
"In terms of content, I think it's done a better job of bringing them back to the concepts that we've been learning when they do the analysis. In the past when they get their data, and then they're just like 'it went farther because like I don't know' and now it's like 'well my claim says that momentum affects how far something goes, that has something to do with momentum, ok, what's momentum, mass and velocity, I changed the mass, oh I must of increased the momentum'. So I think it makes the connections more explicit, I think it makes them more explicit."

<u>Quotes from Brenda's Interview 10-07-05</u>
"I feel like the main difference between Claims-Evidence and regular inquiry is just having the claim and having that connection between the claim and the evidence or the analysis that you're giving or the background information. Just really being able, I think it helps them in some respects be able to tie in scientific concepts better as opposed to just personal experience, because if the claim is a true claim and it includes some scientific concepts that have been covered up to that point then I think if it's at least proposed to the question they feel like they have more access or more ability to use that, kind of like a license to say, 'oh, ok, I get it, I can try to explain that using this concept"

I: Describe how claims-evidence is different from types of inquiry teaching that you did in the past.

TB: Well there's a claim and not just a question. It, I think it, like I said, I think it helps kids focus in on the content they need to know to understand, like most of the time we've covered all of the content they really need to know for the most part to explain and to analyze a question or an inquiry that we're proposing to them or that they're doing, but I just, yeah, I think it, it helps them see the connection better. Moving from what's really easy, like I said, personal experience to know what do I actually know about science that might help me explain that and kind of bridges that gap a little more easily.

Essential Features of Classroom Inquiry (NRC, 2000)

- Learners are engaged by scientifically oriented questions.
- Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate **explanations** from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
- Learners communicate and justify their proposed explanations.

Appendix D: Description of the Inquiry and the Nature of Science Unit

Activity	Description	Content	Inquiry
Mystery Cube	Students made observations of a cube with numbers on it in order to attempt to determine what was on the bottom of the cube. Students made observations (evidence), made a hypothesis based on evidence, conducted an "experiment", identified patterns and proposed explanations.	• Nature of Science (observations, inferences, tentativeness)	• Predictions • Observations • Collecting data • Identifying patterns • Formulate explanations
Nature of Science Notes	Students took notes on the nature of scientific questions and the relationship between evidence and explanations.	• Nature of Science • Understandings about inquiry	NA
Scientific Inquiry Model Activity	Students did a sorting activity where they sorted different components of the scientific inquiry model.	• Understandings about inquiry	NA
Aye-aye video	Students watched a video about a scientist's research on the Aye-aye and then related what the scientist in the video did with the components of the scientific inquiry model. Studies shown in the video are experimental investigation of how the Aye-aye finds food.	• Understandings about inquiry	NA
Data Tables/Graphs/Etc.	Students received reference handouts about how to set up data tables and how to draw graphs.	• Inquiry Skills	NA

Appendix E: Description of the Force and Motion Unit

Activity	Description	Content	Inquiry
Sentences on the Move	Students were provided with a list of words related to Force and Motion and asked to choose 4 and write sentences using the word.	- Varied	NA
Newton's Apple Demo	Demonstration in which a knife is put part way in an apple and then held in the air and the knife is hit with a stick. When this happens the apple appears to move up the knife until it is cut in half and falls. Students made predictions, observations, and wrote explanations following the demonstration.	- 1st Law	- Predictions - Observations - Formulating explanations
Move it…Prove it	Students made predictions and observations about a number of demonstrations related to force and motion. Following explicit instruction on Newton's Laws and Conservation of Momentum they revisited this activity and wrote explanations.	- 1st Law - 2nd Law - 3rd Law - Momentum - Gravity	- Predictions - Observations - Formulating explanations (following explicit instruction on the concepts)
To move … or not to move?	Lab in which students observed the distance that a cart traveled with different amounts of mass. Part 1: Cart at rest and hit with something. Part II: Cart in motion. Distance represented inertia (if more inertia it goes farther or stays more at rest). Students made predictions, recorded data, graphed data, and identified patterns.	- 1st Law	- Predictions - Collecting data - Measurement - Graphing - Identifying patterns
First Law Magic	Students put an empty cup and a cup with water on a paper towel and moved the paper towel to determine which had more inertia, the one with water or the one without.	- 1st Law	- Observations
Read pp. 145-147	??	- 1st Law - Friction	NA
Force and Motion Review Notes (Part 1)	Students defined the terms: mass, inertia, friction, Isaac Newton, Newton's 1st Law of Motion (law of inertia)	- 1st Law - Friction	NA
Inertia Summary	Homework in which students had to explain to a family member why a bowling ball has more inertia than a volleyball. Then	- 1st Law	NA

	that person had to write a summary of what they student said.		
Balloon Zoom	Part I: Lab in which students observed the distance that a balloon traveled with different amounts of mass attached to it. Part II: Lab in which students observed the distance that a balloon traveled with different amounts of air in it. Distance is used as a measure of acceleration. F=ma not explicitly discussed. Students made predictions, recorded data, graphed data, and identified patterns.	• 2nd Law	• Predictions • Observations • Measurement • Graphing • Identifying patterns (correlations)
"Newton's Second Law of Motion" Reading	Students read a section from the text that discussed Newton's 2nd Law. The reading explained that "the acceleration of an object depends on the mass of the object and the amount of force applied" (F=ma).	• 2nd law	NA
Force and Motion Review Notes (Part 2)	Students defined the terms force, acceleration, gravity, Newton's Second Law of Motion. Using F=ma, students determined how changing the force, mass or acceleration would affect the other variables. Discussed positive and negative correlations.	• 2nd law	NA
Volleyball vs Bowling Ball	Students observed balls of different sizes and masses being dropped and observed that balls of similar sizes dropped at the same rate independent of their weight. Students then calculated the force that objects of different masses would have if they were dropped, using F=ma and given that $a = 9.8m/s^2$.	• 2nd Law • Gravity (heavier objects do not fall faster, heavier objects are acted on by more force when they fall)	• Observations • Calculations
Newton's 1st and 2nd Laws of Motion Review	Students answered fill in the blank questions that reviewed Newton's 1st and 2nd Law. Primarily recall questions, one calculation question.	• 1st Law • 2nd Law	NA
Newton's 1st and 2nd Law Pair Share		• 1st Law • 2nd Law	NA
Force and Motion Review Worksheet Parts 1 and 2		• 1st Law • 2nd Law	NA

"Newton's 3rd Law of Motion" Reading	Students read a section from the text on Newton's 3rd Law of Motion. It explained that "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first."	• 3rd Law	NA
Ramp of Ramming	Lab in which students ran a cart down a ramp and investigated how the cart affected the distance traveled by an object that it hit. Part 1: Changed the mass of the cart. Part 2: Changed the velocity of the cart. Relationship between mass or velocity and momentum. Distance used as a measure of momentum. Students collected data, graphed data, and identified patterns.	• Transfer of Momentum	• Collecting data • Measurement • Graphing • Identifying patterns (correlations)
"Momentum" Reading	Students read a section from the test on momentum. It explains the conservation of momentum and provides examples of the transfer of momentum when one object hits another object.	• Momentum	NA
Force and Motion Review Notes (Part 3)	Students defined Newton's 3rd Law of Motion, Velocity, Momentum, Law of Conservation of Momentum.	• 3rd Law • Momentum	NA
Newton's Third Law of Motion Review	Students answered fill in the blank questions. Primarily recall questions, one calculation question about momentum.	• 3rd Law • Momentum	NA
Force and Motion Review Worksheet (Part 3)		• 3rd Law • Momentum	NA
Word Bank	Students defined the following words: Question, Observe, Evidence, Hypothesis, Infer, Explanation, Tentative, Variable, Independent Variable, Dependent Variable, Controlled Variable	• Scientific Inquiry	NA
Rocket Force and Motion Notes	Students took notes on aerodynamic forces including lift, weight, thrust, drag.	• Aerodynamic forces	NA
Water Rocket Force and Motion Notes	Students took notes on how a water rocket works and how its flight relates to momentum.	• Momentum	NA

Appendix F: Bottle Rockets Post-test

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   - A. About half as long for the heavier ball.
   - B. About half as long for the lighter ball.
   - C. About the same time for both balls.
   - D. Considerably less for the heavier ball, but not necessarily half as long.
   - E. Considerably less for the lighter ball, but not necessarily half as long.

   Explain your answer: ____
   ____
   ____

2. Imagine a head-on collision between a large truck and a small compact car. During the collision
   - A. The truck exerts a greater amount of force on the car than the car exerts on the truck.
   - B. The car exerts a greater amount of force on the truck than the truck exerts on the car.
   - C. Neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   - D. The truck exerts a force on the car, but the car doesn't exert a force on the truck.
   - E. The truck exerts the same amount of force on the car as the car exerts on the truck.

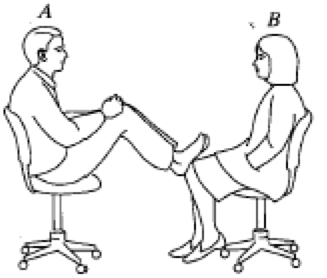
   Explain your answer: ____
   ____
   ____

3. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?
   1. A downward force due to gravity.
   2. The upward force by the table.
   3. A net downward force due to air pressure.
   4. A net upward force due to air pressure.

   - A. 1 only
   - B. 1 and 2
   - C. 1, 2, and 3
   - D. 1, 2, and 4
   - E. None of these since the book is at rest there are no forces acting on it.

   Explain your answer: ____
   ____
   ____

Two students, student “a” who has a mass of 95 kg and student “b” who has a mass of 77 kg sit in identical office chairs facing each other. Student “a” places his bare feet on student “b’s” knees, as shown below. Student “a” then suddenly pushes outward with his feet, causing both chairs to move.



95 kg **77 kg**

4. In this situation,
    A. Neither student exerts a force on the other
    B. Student “a” exerts a force on “b”, but “b” doesn’t exert any force on “a”.
    C. Each student exerts a force on the other but “b” exerts the larger force.
    D. Each student exerts a force on the other but “a” exerts the larger force.
    E. Each student exerts the same amount of force on the other.

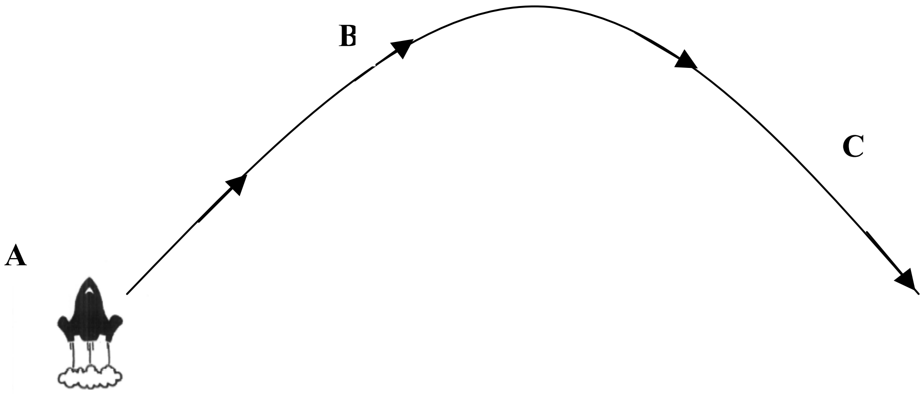
    Explain your answer: ____
    ____
    ____

5. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court. Consider the following forces:
    1. a downward force of gravity.
    2. a force by the "hit."
    3. a force exerted by the air.

    Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

    A. 1 only
    B. 1 and 2
    C. 1 and 3
    D. 2 and 3
    E. 1, 2, and 3

    Explain your answer: ____
    ____
    ____



The diagram above shows the path that a water rocket might travel.

6. In your own words, explain how the water rocket "takes off".

____

____

____

7. How would adding **more water** to the rocket affect
   A. The lift off of the rocket ______________________________________

   ____

   Explain why ____

   ____

   B. The distance the rocket travels __________________________________

   ____

   Explain why ____

   ____

8. Assuming that the amount of water in the rocket is kept the same, how would adding **more mass** to the rocket affect
   A. The lift off of the rocket ______________________________________

   ____

   Explain why ____

   ____

   B. The distance the rocket travels __________________________________

   ____

   Explain why ____

   ____

Appendix G: Scoring Rubric for Bottle Rocket Test

Question 6: Application of third law to water rockets
0 – No answer or no explanation for take-off
1 – Water or air gets pushed out. No explanation of how that affects rocket or reaction is described as ground pushing rocket.
2 – Water gets pushed out which results in an opposite force moving rocket forward.
*Issues – a number of students misread this question and described the flight rather than the take off

Question 7: How does adding more water to the rocket affect the distance it travels?
*The distinction between lift-off and distance was confusing. Therefore analysis of this question focused on students answers related to distance, but used information from both parts of the question.

0 – No explanation or incorrect explanation
- More mass so goes farther.
- Adds more inertia.
- Less space for air pressure, so more pressure built up so goes farther.

1 – Reasonable explanation for an increase or a decrease in the distance
- More water = more fuel
- More water provides more force to move rocket forward.
- Accepted less distance because more mass in the rocket (this is a valid answer past ½ full and the question was not specific enough)

2 – Reasonable explanation for an initial increase and then decrease in the distance

Question 8: How does adding more mass to the rocket affect the distance it travels?
*The distinction between lift-off and distance was confusing. Therefore analysis of this question focused on students answers related to distance, but used information from both parts of the question.

0 – No explanation or incorrect explanation
- More mass, so heavier and more acceleration
- Gravity affects it more if it has more mass.
- Further, has more inertia
- Go further, more mass would give the rocket more momentum. (Misconception that anything with more momentum will travel a farther distance)
- Go further if the mass was in the front rather than the back.

1 – Reasonable explanation
- More mass, harder to push
- More mass, requires more force.
- More mass could stabilize the rocket so it doesn't flop around.

2 – Reasonable explanation for an initial increase and then decrease in the distance

Appendix H: Example of Day-by-Day Description of Instruction

10-20-05: Anne

T = teacher led lecture, WC = teacher guided discussion, SG = small group discussion

Time	Description	Comments	Focus
0:30 – 4:47	Start of class logistics, review of team norms, hand journals out.	Teacher directed. Group discussion while journals handed out – social.	Logistics - T
4:47 –	Table of Contents directions	Teacher directed	Logistics - T
6:38 – 16:15	Rocket Force and Motion Notes	Teacher lecture, teacher asks students for input and rephrases in more scientific terminology. Content – forces acting on rocket (weight, drag, thrust, lift)	Content – WC
16:15 – 17:20	Teacher gives directions for handing out papers.	*Girl group has discussion about confusion over notes	Logistics - T *Content - Girl group
17:20 – 20:55	Water Rocket Class Example (Claim, Question, Hypothesis)	T discusses Work Samples and nature of claims	Content – WC
20:55 – 22:40	Water Rocket Class Example (supporting evidence)	Students discuss supporting evidence for hypotheses. Invoke explanations using scientific concepts.	Content - SG
22:40 – 27:05	Water Rocket Class Example (supporting evidence)	Teacher asks students for input and rephrases in more scientific terminology. Teacher describes what makes good supporting evidence. Need to show how it is connected to claim, question, and hypothesis.	Content – WC
27:05 – 29:20	Word Bank: Variables	Terminology	Inquiry – SG
29:20 – 32:40	Word Bank: Variables	Teacher asks students for input and rephrases in more scientific terminology, then students write down definitions.	Inquiry – WC
32:40 – 33:10	Water Rocket Class Example (DI – Identifying Variables)	Teacher gives directions. Teacher provides some of the controlled variables, asks S's for others.	Inquiry – T
33:10 – 34:40	Water Rocket Class Example (DI – Identifying Variables)	* Boy group discussion of variables refers to relationship between variables.	Inquiry – SG
34:40 – 37:53	Water Rocket Class Example (DI – Identifying Variables)	Teacher asks students for input and rephrases in more scientific terminology, then students write down answers.	Inquiry – WC
37:53 – 45:05	Water Rocket Class Example (DI – General Plan)	T asks students for input on preliminary procedures and rephrases in more scientific terminology, then students write down answers. *Boy group discusses design of rocket during this class discussion.	Inquiry – WC
45:05 – 45:35	Handing in papers	*Boy group discussing who has launchers and how they could test out designs on their own. Continue this discussion through rest of class.	Logistics
45:35 –	Data Table and Graph	Teacher gives directions for pasting info into	Logistics - T

47:15	Info	journals	
47:15 – 52:30	Data Table and Graph Info	Students glue pages into journal. *Boy group starts by discussing where to launch rocket, then discussion turns mainly social. *Boy group asks teacher about launching rocket at home. Teacher says sure.	Logistics - T
52:30 - 53:40	End of class clean-up		Logistics
53:40 – 55:45	Planners		Logistics
55:45 – 56:45	Discussion of what materials to bring for water rockets.	*Boy group discusses what to use as materials, some discussion of what will work better (difficult to hear).	Logistics - SG

Appendix I: Instruction Code List

Theme	**Macrocode**	**Microcode**
Explanations	Epistemological approach to claim	• Claim backed by evidence • Claim as true • Claim frames investigation
	Connection between claim and investigation	• Connection between claim and question • Connection between claim and investigation
	Encouraging explanations	• Supporting evidence • Explaining results
Claim (scientific concepts)	Concept development	• Prior instruction • Clarification of concept
	Nature of the claim	• Complexity • Relationship to questions
Inquiry	Developing inquiry skills and understandings	• Forming Questions • Hypotheses (definition) • Hypothesis (modeling) • Methods (Data Range) • Methods (Data Table) • Methods (Measurement) • Methods (Observations) • Methods (Variables) • Methods (Procedures) • Analysis (Calculations) • Analysis (Graphs) • Analysis (Results/Conclusion) • Analysis (Errors/Limitations)
	Nature of the task	• Good data • Unexpected results
Logistics		
Off-task		

Appendix J: Explanations Code List

Macrocode	**Microcode**
Concept	Claim – Conservation of Momentum First Law (inertia) Second Law (F=ma) Third Law (action-reaction) Relationship between acceleration and mass Relationship between momentum and inertia Thrust Force Momentum Gravity Aerodynamics Water Rocket Force and Motion Notes
Analogy	Personal Experiences • Fuel • Vinegar and baking soda • Shaking pop • Squashing water bottle Classroom Experiences • Watching prior water rocket launches • Balloon Zoom
System	Relationship between air pressure and water Relationship between water and mass

Appendix K: Scientific Inquiry Work Sample Handout

FORMING A QUESTION OR HYPOTHESIS

Claim (Write the **claim** for which **evidence** will be gathered.)

____

____

____

Question (Write a **question** related to the above **claim** that can be **answered** by **gathering data** in a scientific investigation.)**:**

____

____

____

Hypothesis (Write a **hypothesis** that can be **tested** by **gathering data** in a scientific investigation.)

____

____

____

Supporting Evidence for Hypothesis (Write down information you already know that is **relevant** to the **claim**, **question**, and **hypothesis**.)
•Scientific Facts, Ideas, Concepts:

____

____

____

____

____

•Personal Experiences:

____

____

____

____

DESIGNING AN INVESTIGATION

Identifying Variables

List the variables that are most important in this investigation.

Independent Variable (Which variable will you **change** on purpose?)	**Dependent Variable** (Which variable **may** respond to the change in the independent variable?)

Controlled Variables (Which variables do you want to keep the same during your investigation so they won't affect the outcome of the investigation?)

General Plan:

Make a general plan for collecting the necessary data.

•What **materials** will you need and how will you set them up?

______________________________________ diagram(s)

____

____

____

•What are the ways you will **change** your **independent variable**?

____

____

____

•How will you **measure** your **dependent variable**?

____

____

____

DESIGNING AN INVESTIGATION (continued)

In the space below, write a list of **materials** you used during the investigation.

Materials:

Write a **numbered** set of **specific procedures** you followed during the investigation that are **logical**, **safe,** and **ethical**. Include diagrams or pictures which may help describe your procedures.

Diagrams: **Procedures:**

COLLECTING AND PRESENTING DATA

Record your **OBSERVATIONS** by **writing** and **drawing** diagrams of the information you gathered by using your senses.

____ diagram(s)

____

____

____

____

____

____

____

Record data that matches your procedure. Make sure the **DATA TABLE** is **complete** and **organized** with the correct **variables** and **units**.

TITLE:____

COLLECTING AND PRESENTING DATA (continued)

Transform your data into a **GRAPH** to look for **patterns** or **trends**. Make sure your graph is **complete** and **organized** with **correct variables** and **units**.

TITLE:____

ANALYZING AND INTERPRETING RESULTS

Results (Describe the evidence you gathered by using your specific data to state your **average results**.)

Conclusion (State your **conclusion** by answering the **question** and addressing the **claim**. Include **patterns** and **trends** suggested by the average data.)

Explanation (**Explain** how your **results/evidence** support the **claim** using **scientific concepts, facts** and **ideas**.)

Review Your Design (Describe some possible **limitations** of your procedures or equipment and any **errors** in your data that may have prevented more accurate results in the investigation.)

New Questions (Write new questions you have about force and motion based on your results.)

Appendix L: Analysis of Student Explanations Linking Evidence to the Claim

Key: a) = explanations for increasing distance
b) = explanations for decreasing distance
→ = Connection between two variables
Bold = Line of reasoning about momentum
Italics = Implied but not explicitly stated
[ ] = Supporting Statements or Qualifiers

w = water leaving the rocket
r = rocket
a = air pressure
g = ground

Explanations attempting to link results to the Claim (Water Question – Results Show Increase Only)

Model Explanation:

	a) < ½ Water	**More Water → More Mass (w) → More Momentum (w) → More Momentum (r) → More Velocity (r) →**	**More Distance**	
1.	a)	**More Water → Momentum →**	**More Distance**	[TB5033]
		Momentum has inertia and the rocket continues moving / resting unless acted on by unbalanced force {gravity}, 3rd Law	**More Distance**	
2.	a)	**More Momentum → Rocket in motion longer**	***More Distance***	[TB5008]
		[Newton's 3rd Law – for every action there's a reaction] →	*More Distance*	
		Changing Water → Air pressure pushes water faster →	More Distance	
	b)	Too much water →	*Less Distance*	
3.	a)	**Water → More Momentum (r) →**	**More Distance**	[TB4012]
		More Water → More Fuel →	More Distance	
		[Water in rocket acts like fuel in a car]		
4.	a)	**Water/air → Mass (r) → Mass in motion → Momentum**	***More Distance***	[TB5005]
5.	a)	**More Water → More Compacted Air → More Force → More Momentum →**	**More Distance**	[TB5020]
		[Newton's 2nd Law – acceleration depends on mass and amount of force → Distance depends on air pressure and amt of water in bottle]		
6.	a)	**More Water →** More Force pushing on rocket → More Force pushing back on air and rocket [3rd Law]	*More Distance*	
		More Water → More Force → More Velocity (w) → More Momentum	***More Distance***	[TB5034]
7.	a)	**More Water → More Force on air pressure → More Velocity (w) → More Momentum transferred →**	**More Distance**	[TB4013]

8. a) **More Water →** **More Mass →** **More Momentum (w in downward motion) →** **More Momentum (r in forward motion) More Distance** [TB4017]
[3rd Law says that for every action there is a reaction]
[Downward motion of water creates momentum that depends on the mass and velocity of the water]
[Forward motion of rocket is equal and opposite in direction to the momentum of the water]
[More momentum of water results in more momentum of rocket, because of the equal and opposite reaction]

9. a) **More Water (fuel) →** **More Momentum** [TB6021]
More Mass → More Force (a) → Velocity *(w)* → More Momentum (w) → **More Momentum (r) →** **More Distance**
[3rd Law]

Explanations attempting to link results to the Claim (Water Question – Results Show Decrease Only)

Model Explanation:
b) > ½ Water **More Water →** **Less Volume (a) → Less Mass (w) →** **Less Momentum (w) → Less Momentum (r) →** **Less Velocity (r) → Less Distance**
More Water → **Less Volume (a) → Less Mass (w) →** **More Mass (r) →** **Less Velocity (r) →** **Less Distance**

10. b) **More Water →** **Changes Momentum →** ***Less Distance*** [TB5015]
[Momentum remains constant and is only changed by the action of forces]
Force (a) → Built up momentum for the rocket to fly
[Momentum remains constant unless acted upon with equal amount of force, which could be wind, ground, or the wall]

11. b) **More Water →** **Less Momentum →** ***Less Distance*** [TB6027]
[not a big enough exit hole for all of the water to escape]
More Mass/not enough force → *Less Distance*

12. b) **More Water →** **Less Momentum (w) → Less Momentum (g) → Less Momentum (r) →** ***Less Distance*** [TB6023]
[All the water can’t escape]
More Water → More mass/not enough psi → *Less Distance*

Explanations attempting to link results to the Claim (Water Question – Results Show Increase, then Decrease)

Model Explanation:

a) < ½ Water **More Water →** **More Mass (w) → More Momentum (w) → More Momentum (r) → More Velocity (r) → More Distance**

b) > ½ Water **More Water → Less Volume (a) → Less Mass (w) → Less Momentum (w) → Less Momentum (r) → Less Velocity (r) → Less Distance**

More Water → Less Volume (a) → Less Mass (w) → More Mass (r) → Less Velocity (r) → Less Distance

13. a) **Momentum (r) →** **More Distance** [TA2027]

14. [Newton's 2nd Law: Force = mass X Acceleration]
More Mass → More Force needed to get the Same Acceleration
0ml Lots of space for air pressure, but Little Mass → Strong Acceleration, but nothing to keep it going *Little Distance*
1/2 full Half the space left for air pressure → Mass and Force Accelerated → More Distance
Full No room left for air pressure → Lots of mass & Not enough Force → Couldn't transfer its energy to the rocket → *Less Distance*
[water didn't have enough time to escape]
[Law of Conservation of Momentum didn't have enough time to work to its full potential]

15. **Momentum (moving mass of rocket) → Momentum (w & a) →** **More/Less Distance** [TA5028]
[Conservation of Momentum, Momentum (w & a) transferred in opposite direction]
a) < ½ Water **30psi (momentum) had enough pressure and energy to push water out →** ***More Distance***
b) > ½ Water Too Much Mass for air pressure to push out → *Less Distance*

16. a) **Momentum (w) →** **Momentum (r) →** **More Distance** [TB5018]
[Law of Conservation of Matter (Momentum) really kicked in during heavier trials]
[3rd Law helped because when the water flew out (action), rocket went farther (reaction)
b) Water → More Mass → More Inertia *Less Distance*

17. a) **Momentum (water/fuel) → Momentum (g) → Momentum (r)** ***More Distance*** [TB6016]
[If mass and force are balanced]
b) More Water → More Mass → Resting Inertia → More force needed → Less Distance

18. a) **More Water →** **More Momentum** ***More Distance*** [TB6004]
b) More Water → More Mass/Less Volume (a) *Less Distance*
[Not enough room for air pressure]

19. a) **More Water →** **Momentum (w) →** **More Distance** [TB6031]
[Water pushes on air]
b) More mass → More force pulling it down → Less Distance

20. a) <2000ml **More Water →** **More Potential for More Momentum →** **More Distance** [TA3025]
More water → Bigger Reaction → More Distance
[Newton's 3rd Law]
b) 2000ml [until too much water to push out, air didn't have enough force, can't make use of rockets potential for greater momentum] → *Less Distance*

21. a) **More Water →** **More Action Force (w) →** **More Reaction Force (momentum) →** **More Distance** [TA5027]

22. a) **Some Water →** **Momentum →** **More Velocity (r) →** ***More Distance*** [TA5008]
[Used air to use momentum of rocket]
b) **More Water →** **Same Momentum → Less water leaving rocket → Slower rocket** ***Less Distance***
[so much water, couldn't get out of rocket fast enough, holding rocket down]

- -

23. a) <1500ml **More Mass →** **More Momentum →** **More Distance** [TB4006]
b) >1500ml [Couldn't have too much mass] → Less Distance

24. a) <1500ml **More Mass →** **More Momentum →** **More Distance** [TB4019]
b) >1500ml [Couldn't have too much mass] → Less Distance

25. a) <1,500ml **More Mass →** **More Momentum →** **More Acceleration (r)** ***More Distance*** [TA2012]
b) >1,500ml [Until mass gets too great for the force] → *Less Distance*

26. b) **More Water →** **More Mass →** **More Momentum →** **Less Distance** [TA2010]
[2nd Law – more mass] → Less Distance

27. b) Same Force & More Mass
More Momentum → More Weight → **Less Distance** [TA1029]

28. a) **More Water →** **More Mass →** **More Momentum** ***More Distance*** [TB5009]
b) [unless too much mass] *Less Distance*

29. a) <1500ml **More Water →** **Mass →** **More Inertia / More Momentum** ***More Distance*** [TA3003]
b) 1500ml Too much mass → Less Distance

30. a) **More Fuel →** **More Mass →** **More Momentum →** ***More/Less Distance*** [TB5029]
[Air pressure has more to push on]
[When it gets too heavy it would be harder to push]

- -

31. b) More Water → More Mass (r) → *Less Distance* [TA4014]
[Not all the mass of the water leaves the rocket]
More Force → More Momentum

32. a) **More Force → More Momentum (r) → More Distance** [TB5016]
[Conservation of momentum says if force increases, momentum increases]
b) [Decrease at 750ml due to error] *Less Distance*

33. b) **More Water → More Force btw w & a → More Momentum (btw w & a) → Less Force to push water → Less Distance** [TA2021]

34. a) <1200ml [More air pressure, relative to when more water] **More Force →More Momentum → More Distance** [TB6032]
b) >1200ml More Water →Less Air Pressure → Less Lift Less Distance
More Water → More weight → *Less Distance*
[Only some of the water got out]

35. a) <1/2 Water **More Water → More Velocity → More Momentum → More Distance** [TB5004]
[Momentum Conserved]
b) >1/2 Water More Water → More Mass → More Inertia → Water will keep wanting to go the way it's going, but unbalanced force of gravity acts on it. [1st Law]

36. a) <1200ml **More Water → More Mass More Acceleration → More Momentum →** ***More Distance*** [TA2015]
[Due to water being pushed out] [Acceleration determined by mass and force]
b) >1200ml [Same Force, Mass too great for the force] → Less Distance

37. [Conservation of Momentum: water and air pressure pushing on each other with the same amount of force] [TB6017]
More Water → Requires more air pressure → More Velocity (w) → More momentum → More Distance
But - Air pressure stays the same → Water pushed out with same force Same Distance
No Water Compressed air had nothing to push on (no fuel) → No Distance

- -

38. **No Water → Little Mass → Little Momentum (r) →** ***Little Distance*** [TA5006]
a) **1,000ml Water → Lots of Momentum (r) →** ***More Distance***
[Propelled through the air with lots of force]
b) **2,000ml Water → Too Much Mass → Little Momentum (r) → Little Distance**

39. a) <1,000ml **More Water & Air Pressure→** **More Momentum (w)** ***More Distance*** [TA3013]
[Force/Air pressure creates momentum]
b) >1,000ml More Water → Mass (r) → Less Distance
[Not all water is able to be pushed out]
[Newton's 2nd Law – acceleration depends on mass and force applied]
Water left in rocket → More mass (r) → Same force = Less Acceleration → Less Distance

40. a) **More Momentum →** **More Motion** **More Distance** [TB5028]
Enough Air pressure → More Velocity (w) → **[transfers] More Momentum (r)** ***More Distance***
Downward motion of Water (mass X velocity) → **Creates Momentum**
b) **Less Momentum →** **Less Motion** **Less Distance**
More Water → More Mass → More Inertia Less Distance
[1st Law - Inertia is the tendency for an object to continue doing what it is doing moving or resting]
[1st Law – If an object has more inertia it will take more force to start stop or change the direction of the object]
[Air pressure couldn't send it as far, because required more force to move water out of rocket]
a) **More Water →** **More Mass →** **More Momentum →** **More Distance**
b) **[BUT]** **More Mass → Less Velocity (w) → Less Momentum (w) →** **Less Momentum (r)** ***Less Distance***

Explanations attempting to link results to the Claim (Mass Question – Results Show Increase, then Decrease)

Model Explanation:

	a)	More Mass (r) →	Changes center of gravity → Stabilizes flight →			More Distance	
	b)	**More Mass (r) & Constrained Momentum (w) →**		**Same Momentum (r) →**	**Less Velocity (r) →**	**Less Distance**	
41.	a)	**More Mass →**		**More Momentum →**		**More Distance**	[TA4022]
	b)	More Mass → Weighed more →			Slowed it down→	Less Distance	
42.	b)	**More Mass →**		**More Momentum →**		**Less Distance**	[TA5013]
43.	a)	More Mass (r) →	More Inertia →		Longer Flight →	*More Distance*	[TA5003]
	b)	Too Much Mass (rocket) →			Can't continue in motion →	*Less Distance*	
		More Mass (r) →		**More Momentum (r)**			
		[Newton's 2nd (1st?) Law – more inertia more the object will stay in motion or at rest]					
44.	b)	More Mass →				Less Distance	[TA5019]
	a) 100g					More Distance	
	b) **0g**	**No Mass (r) →**		**No Momentum**		***Less Distance***	
		More Mass (r) →		No Inertia			

Explanations attempting to link results to the Claim (Mass Question – Results Show Decrease Only)

Model Explanation:

	b)	**More Mass (r) & Constrained Momentum (w) →**		**Same Momentum (r) →**	**Less Velocity (r) →**	**Less Distance**	
45.	b)	**More Mass (object) → "Law of Conservation of Momentum" pushes back on object →**				**Less Distance**	[TB4024]
		More Mass → More gravity is pushing down on it					
		More Mass (object) → More Momentum transferred back on object →				***Less Distance***	