DEVELOPING SCIENTIFIC LITERACY THROUGH CLASSROOM INSTRUCTION: INVESTIGATING LEARNING OPPORTUNITIES ACROSS THREE MODES OF INQUIRY-BASED SCIENCE INSTRUCTION

by

Debi Khasnabis

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Doctoral Committee:

Professor Annemarie Sullivan Palincsar, Chair
Professor Jean P. Krisch
Associate Professor Elizabeth A. Davis
Associate Professor Lesley Ann Rex

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Prologue

The research conducted as part of this dissertation study may seem unusual for a student of Educational Studies in Literacy, Language and Culture. Indeed, at first blush, the conceptual terrain of this work may appear to be more typical for a student of science education. However, several circumstances have led me to this terrain, which lies at the complex and rich intersection of science and literacy education.

In the early years of my career, I spent five years as an elementary school teacher in Detroit, Michigan. I spent most of this time as a bilingual homeroom teacher working with children of diverse cultural and language backgrounds. I also studied the discipline of bilingual education and earned an Educational Specialist certificate in Curriculum and Instruction for Bilingual and Bicultural Education at Wayne State University. These experiences exposed me to a wide range of challenges that children like my students confronted on a daily basis. Amongst these numerous challenges, I became particularly concerned about my students' shallow exposure to the content areas apart from math and reading. In conversation with teachers and administrators, both at the school and district level, I repeatedly found that many educators believed that English language learners (ELLs) first needed to master literacy before they could learn discipline-specific content. The assumption was that the language demands of learning science and social studies were too high for ELLs to handle. Thus, I found that it was common for bilingual students to be given an extra period of gym or keyboarding for a "special" when other students in the school received specialized science instruction from the school science teacher. Policies such as these deeply troubled me.

At one point, I volunteered my time to serve on a science textbook adoption committee for the district's bilingual education students. The premises of the committee's formation and the commercial development of these texts were well-founded: educators and curriculum developers were recognizing that all students, including ELLs, needed to have access to rich content learning. But I was disappointed by what I considered to be a dismal array of curricular options. The texts that were being considered for my students tended to relate the same content as that taught to mainstream students by using simplified language, providing more graphic organizers, and boldfacing important concepts and vocabulary words. I did not believe that science could be learned in this way. As part of my coursework at Wayne State and through the knowledge I had gained working with my students, I had come to believe that the learning of language and literacy could be especially powerful when language was used to meaningfully engage with content-specific practices and concepts. I also came to understand that it was important to acquire scientific literacy in this way. My students were lacking the experience of scientific inquiry, both on procedural and conceptual grounds. I knew that they would not gain this knowledge by reading boldfaced words and concepts.

Concerns such as these were what led me to pursue a doctoral degree in Educational Studies in Literacy, Language and Culture. I saw that content-specific disciplines offered a rich means for students to meaningfully acquire literacy; and at the same time, it was critical for students to gain these types of subject-specific literacies in order to succeed in the disciplines. While applying to graduate school and during my graduate coursework and research, I learned that many researchers were engaged in examining these very issues. Broadly speaking, the literacy education community had been very interested in building bridges to the science education community. For example, I studied the work conducted by Jay Lemke (1990) and Jim Gee (1996) who examined the community-specific discourse practices of various disciplines; and when I first came across Wendy Saul's (2004) edited volume, *Crossing Borders in Literacy and Science Instruction*, I was thrilled to learn of the complex ways that researchers had considered numerous aspects of the science and literacy intersection, ranging from issues of access (Feldman, 2004; Guzzetti, 2004; Kamil & Bernhardt, 2004) to issues of professional development (Dyasi & Dyasi, 2004).

In fact, while applying to graduate school, it was during my very first meeting with my then would-be advisor, Annemarie Palincsar, that I learned of the ongoing efforts that Annemarie and her colleagues had made to help children develop scientific literacy through the use of innovative science texts. With the use of these texts, students were participating in scientific inquiry in language-rich ways. I was intrigued and excited at the prospect of participating in and learning from this type of innovation. Indeed, several years later, this body of research is what has given birth to my dissertation study. I believe that this dissertation study is a testament to the strides I have made in addressing the deep concerns I faced as a teacher of young children who were rarely offered the rich quality of science and literacy instruction that they deserved.

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CHAPTER 1: INTRODUCTION

The Educational Problem

In recent years there have been an unprecedented number of calls from national organizations for improved K-12 science instruction that would attract more American students to science-related fields (American Electronics Association (AEA), 2005; Association of American Universities (AAU), 2006; Augustine, 2007; Business Roundtable (BR), 2005; Glenn Commission, 2000; National Association of Manufacturers (NAM), 2005; National Science Board, 2004). Augustine (2007) reported that of all the recommendations posed by the *Rising Above the Gathering Storm* national committee (supported by the National Academy of Sciences), the committee's unanimous highest priority was to improve K-12 education, particularly in the disciplines of math and science. These urgent calls have emerged out of the growing recognition that the American educational system is not adequately preparing students for contemporary challenges. For example, in 1998, the Third International Mathematics and Science Study (TIMSS) reported that, by the time U.S. students reach their senior year of high school, they rank below their counterparts in 17 other developed countries in mathematical and scientific literacy (Gonzales, Guzmán, Partelow, Pahlke, Jocelyn, Kastberg, & Williams, 2004).

It is within this context that a critical need for research that informs the implementation of improved science instruction has evolved. Florio-Ruane (2002) warned that when a climate of crisis prevails, the public tends to look to research for the authority, efficiency, and simplicity that is associated with a nomological paradigm. But she argued that educational researchers must resist this temptation:

> We can study human thought and activity in the light of this paradigm, seeking law-like generalizations about how teachers think and also what kinds of knowledge they need to make good pedagogical decisions. However, it is of limited use for purposes of understanding thoughtful action in context, a kind of research useful to teachers and administrators more locally. To understand local knowledge in teaching and teacher education, we needed in-depth studies of individual teachers at work and of the variety of ways that teachers think about and do that work. (p. 209)

Thus, Florio-Ruane recommended that research may be most helpful when it thoughtfully reveals the complexity of teaching at the local level, thus guiding teaching practice by illuminating or shedding "more light" into the black box of teaching.

Studies that closely examine teaching at a local level also illuminate the necessary dynamism or interaction between teachers, students, and curriculum materials (Ball & Cohen, 1996; Brown & Edelson, 2003; Cohen & Ball, 1999; Remillard, 1999, 2000). Cohen and Ball (1996) argued that it is important for research to attend to these interactions as they necessarily shape the instructional capacity of any instructional endeavor. Puntambekar, Stylianou, and Goldstein (2007) also called specifically for this type of research:

> To understand the learning environment, it is essential to examine the many variables that might affect student learning, particularly when the same intervention is being implemented in multiple contexts. Very often, this means a systematic analysis of enactments in a setting, in an effort to understand the factors in a local context that may or may not have led to the success of an intervention. One of the main aspects of such an analysis is studying classroom interactions to develop an understanding of the factors that might have contributed to student learning. (p. 121)

Thus, this dissertation study is situated within a historical context of "educational crisis." But rather than succumb to the temptation to provide broad generalizations about teaching and learning, this study attempts to shed light on the complexities of teaching. The study involved a high-quality detailed analysis of inquiry-based science instruction at the elementary level as it was implemented by three university-based guest teachers.

The National Stage

As a nation, we have not prepared our youth for the radical changes and rapid growth in scientific knowledge and technological power that prevail today (American Association for the Advancement of Science (AAAS), 1990). While issues such as the environment and medical innovation are of paramount significance, our nation suffers a shortage of qualified citizenry in the areas of science, technology, engineering, and mathematics (Symonds, 2004; Augustine, 2007). Furthermore, the U.S. confronts a shortage of qualified science teachers (Glenn Commission, 2000; Symonds, 2004; Augustine, 2007); and a wave of retirements - as the baby boom generation ages - will affect not only the teacher job force (Glenn Commission, 2000), but the entire corps of workers with skills in mathematics and the sciences (AEA, 2005; BR, 2005; National Science Board, 2004). The need for science education reform and for improvements in teacher education could not be more pressing (Frelindch, 1998; Nelson, 1999).

It is under this pressing set of historical circumstances that U.S. students continue to underachieve in the domain of science. International rankings of science performance from the Third International Mathematics and Science Study (TIMMS) demonstrate that American 4th and 8th grade students perform satisfactorily, with 4th graders ranking at 6th of 25 countries and 8th graders ranking at 9th of 45 countries (Gonzales, Guzmán, Partelow, Pahlke, Jocelyn, Kastberg, & Williams, 2004). However, by 12th grade, these mediocre rankings plummet to nearly the bottom of the ranks, with students ranking at 16th of 21 countries. In the domain of physics, 12th graders rank at the very bottom of 16 countries participating. The National Assessment of Educational Progress (NAEP) results are similarly disillusioning. In 1996, less than one-third of all U.S. students in grades 8 and 12 performed at or above the proficient achievement level in science (Grigg, Lauko, & Brockway, 2006). More than one-third of students scored below the "basic" level, indicating that they lacked mastery of the prerequisite knowledge and skills needed for grade level proficiency. These staggering figures leave much to be desired for the youth of our nation and their futures. Without the knowledge to compete in today's technological age, our youth will be unable to meet the country's demands for a highly skilled workforce. They will be the ones to suffer the consequences, due largely to the lack of foresight and preventative action of the generation before them.

Many have likened the gravity of this situation to that of the challenge posed by the launch of Sputnik in 1957 (AEA, 2005; Augustine, 2007; BR, 2005; NAM, 2005). The difference, however, is that Sputnik mobilized our nation to adopt an immediate action plan to become a top, if not the top, competitor in a rapidly advancing technological age. The speculation is that the U.S. has become complacent, so comfortable in its prosperity that it cannot sense the winds of change and global competition. The Business Roundtable, an association of chief executive officers of leading American companies, convened a task force that wrote, "If we wait for a dramatic event – a 21st-century version of Sputnik – it will be too late. There may be no attack, no moment of epiphany, no catastrophe that will suddenly demonstrate the threat. Rather, there will be a slow withering, a gradual decline, a widening gap between a complacent

America and countries with the drive, commitment and vision to take our place" (BR, 2005, p. 5).

The problem our nation must confront is formidable. But in one sense, the solution is not that complicated. As Augustine remarked, there is a straightforward, old-fashioned solution: "Get out and compete." He goes on, "…in the 21st century, a developed nation can either innovate or evaporate. It can invest in the future, or it can enjoy the present until the present becomes the past" (p. 67). At the foundation of this grave national problem is one basic problem: the inability of our nation to produce a high quality workforce that can compete in a technologically dependent world. The Glenn Commission (2000) argued that, if America's students are to improve their mathematics and science performance in order to succeed in today's world, the most direct route to achieving this goal is better mathematics and science teaching.

Research has long established that inquiry-based instruction is the most effective - and thus most recommended - approach to science instruction (AAAS, 1990; National Research Council (NRC), 1996; 2000; 2006). This type of instruction was recommended by the National Science Education Standards (NRC, 1996) and reaffirmed again a decade later in the NRC (2006) document "Taking Science to School," as the preferred approach to teaching the acquisition of scientific understanding. The standards describe inquiry as "a set of interrelated processes by which…students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a right understanding of concepts, principles, models, and theories" (p. 214). This recommendation emerges from studies of effectiveness. Inquiry-oriented science instruction has been shown to improve many aspects of children's scientific knowledge.

The NRC (2000) argued that inquiry instruction is effective for achieving conceptual understanding of science principles, comprehension of the nature of scientific inquiry, development of the abilities for inquiry, and a grasp of applications of science knowledge to societal and personal issues (p. 126). In addition, it has been argued that inquiry instruction may effectively narrow the gap between low- and high-achieving students while still being beneficial for high-achieving students (White & Frederiksen, 1998).

In high-quality science teaching, the process of inquiry is at the heart of instruction, mirroring science as it is practiced by scientists. DeBoer (2004) explained, “Inquiry teaching mirrors scientific inquiry by emphasizing student questioning, investigation, and problem solving. Just as scientists conduct their inquiries and investigations in the laboratory, at field sites, in the library, and in discussion with colleagues, students engage in similar activities in inquiry-based classrooms” (p. 17). Generally speaking, inquiry-oriented instruction engages students in exercises where they can both learn and apply content. It focuses on skills such as observation, information gathering, sorting, classifying, predicting and testing, all in the service of learning content. Students are encouraged “to try new possibilities, to venture possible explanations, and to follow them to their logical conclusions…. to submit their work to questioning by others, to pull things apart and put them back together, and to reflect on how conclusions were reached” (Glenn Commission, 2000, p. 22).

The Glenn Commission (2000) criticized current science learning as superficial where students’ grasp of science as a process of discovery is often “formulaic, fragile, or absent altogether” (p. 10). Most science students spend instructional time learning definitions or labels that apply to natural phenomena and scientific processes. They are rarely asked to master the big ideas that lead to a stronger conceptual understanding of the domain. The Commission noted that, for a field whose core is characterized by inquiry, students' learning experiences are limited to understanding "what" and are rarely extended to understanding "how," "why," or "Why should I care?" A recent study confirmed this evaluation by assessing the quality of mathematics and science instruction in 350 representative lessons over the course of 18 months (Weiss & Pasley, 2004; Weiss, Pasley, Smith, Banilower, & Heck, 2003). The study found that only 15 percent of lessons were high in quality, with 27 percent judged as medium and 59 percent judged as low. Fewer than one in five lessons were intellectually rigorous, including effective teacher questioning or guiding students in making sense of the lessons' content. In an earlier national survey of science teachers, (Weiss, Banilower, McMahon, & Smith, 2001), though half of the elementary school teachers reported engaging students in scientific investigations at least once a week, only 37% emphasized scientific inquiry skills, and only 8% emphasized argumentation skills based on scientific evidence.

What is to blame for this current state of instruction where there is little focus on what is actually the heart of the domain? One explanation is that inquiry-focused instruction requires resources, such as time, for teachers to engage in reflection and sharing with colleagues, as well as time for instruction, that are limited in our nation's educational settings. Another likely explanation is that it is an extremely demanding form of instruction. Successful implementation depends upon teachers' knowledge, not only of the scientific content they are teaching, but also of the kinds of pedagogical moves that are likely to engage students in successful inquiry experiences (Cohen, 1989; Shulman, 1987) and that will provide opportunities for students to attain desired scientific literacy skills. Weiss and Pasley (2004), on representative science lessons, also found that lessons leaning toward a reform-oriented inquiry approach were not necessarily higher in quality, suggesting that merely implementing inquiry is not enough. Insuring its success is not an easy task due to the demands of instruction.

Study Overview

This dissertation study addresses a critical gap in the literature. Very few studies have investigated successful enactment of inquiry-based science teaching. Such studies could contribute to the design of specialized curricula that offer teachers the targeted assistance recommended by Weiss and Pasley (2004), based on the results of their study. This assistance could help teachers by identifying the key learning goals for an activity, sharing the research on students' cognitive development in a specific content area, suggesting questions and tasks that teachers can use to monitor student understanding, or outlining the key points that the teacher should emphasize to guide students in scientific sense making (Weiss & Pasley, 2004). Such an orientation to curriculum materials, where teachers are supported in their learning through curriculum development and teaching, has been described as educative curricula (Davis & Krajcik, 2005).

My study addresses this issue by conducting and reporting upon a close examination of the inquiry-based science instruction of three teachers who utilize varied modes of instruction for inquiry-based science. The study examines the learning opportunities afforded by the implementation of three unique modes of inquiry-based science instruction with fourth grade students. The three modes of instruction are first-hand investigation, second-hand investigation, and an interplay of first- and second-hand investigation, as named by Palincsar and Magnusson (2001). In the context of this study, first-hand investigations are investigations where children engage in experiences related to the phenomena they are investigating. In contrast, second-hand investigation involves the conduct of inquiry through written text by reading about what others have claimed regarding the nature of the physical world. The study investigates the way that children acquire the knowledge of scientific literacy, including both syntactic and substantive knowledge, through these three modes of guided inquiry science instruction. The specific research questions are the following:

1. *What are the differential opportunities for students to engage with scientific practices and to acquire accurate conceptual understandings in a first-hand, second-hand or first-hand followed by second-hand investigation?*

2. *What mediates the learning opportunities for engaging with scientific practices and acquiring accurate conceptual understandings across and within conditions?*

In these research questions, and throughout my study, I broadly associate scientific practices with the syntactic knowledge or scientific process skills that children engage in to develop conceptual or substantive understandings. This broad association is based on a more detailed description of scientific practices suggested by the NRC. The NRC (2006) explained that engagement in scientific practices occurs when learners wrestle with meaningful scientific problems in ways that involve social interaction, appropriation of scientific language, and the use of scientific representations and tools. The NRC elaborated, explaining that the practice of science involves "scientific reasoning but also the social interaction that can realize these scientific processes (e.g. scientific arguments are to persuade peers of the claims and their interpretations) and the specialized discourse that provides the precision to communicate about these scientific tasks (e.g., language for evaluating explanations on plausibility, simplicity, and fit with evidence).”

The research questions were investigated through two analytical phases of a qualitative study. The first phase of analysis was a macro video-analysis where I attended broadly to the scientific practices and conceptual understandings that students were engaged with throughout all the instruction that occurred. The second phase of analysis was a microanalysis, where I developed three sets of contrastive case studies that illuminated the range of opportunities for students to engage with scientific practices and conceptual claims through the first-hand investigation and second-hand investigation instructional modes and differential teaching and learning practices within those modes of instruction.

This study is unusual in that it investigates guided inquiry science instruction closely over a sustained program of inquiry in a particularly challenging problem space that upper elementary school teachers are responsible for teaching (mass-motion and force-motion relationships on inclined and horizontal planes). In addition, the university-based guest teacher-researchers who were studied have high expertise in this content area, thus enabling focused examination on differential instructional moves across conditions and teachers, independent of differences in teacher content knowledge.

The findings of the study illuminate curricular affordances of different modes of instruction for inquiry-based science and the teaching moves that bring these affordances to life. My study shows how the interplay between curricular affordances and teacher moves can collectively lead to rich scientific literacy learning opportunities for upper elementary students. The findings also tend to reveal affordances of the second-hand investigation instructional mode and challenges associated with implementing instruction that features first-hand investigation. Thus, they have critical implications for teacher education and for educational reform that will support teacher educators to provide preservice teachers with the knowledge necessary for implementing high quality science instruction.

Chapter 2 of this dissertation consists of a literature review on the theoretical ideas and research findings that informed the design, conduct, and interpretation of this study. In Chapter 3, I describe the research design of this study, including descriptions of the Guided Inquiry supporting Multiple Literacies (GIsML) program of research, which provided the data utilized in this study, and the methods used for data collection and analysis. Chapters 4 and 5 comprise the results of the study. The results reported in Chapter 4 were based on the macro-analysis of the entire video-based data set and are responsive to the first research question. Based on my analysis, I discuss the differential opportunities for engaging in scientific practices and acquiring accurate conceptual understandings across the three modes of inquiry-based science instruction. Chapter 5 is responsive to the second research question. It reports my findings based on a cross-case analysis of the three sets of contrastive cases. This portion of the study involved a microanalysis of the instructional settings that led to the relatively richest and leanest opportunities for engaging with scientific practices and conceptual claims during the first week of the study's implementation. The close analyses conducted across these contrastive cases demonstrate what mediates the learning opportunities for engaging in scientific practices and acquiring conceptual understanding across and within the unique modes of inquiry-based science instruction. Finally, Chapter 6 highlights the main findings and discusses the limitations and implications of this work for teaching and research in science and literacy education.

CHAPTER 2: LITERATURE REVIEW

Overview

The purpose of this literature review is multifold. The studies reviewed here set forth the theoretical and empirical bases that informed the design, conduct, and interpretation of this study. The purpose of the study was to analyze the inquiry-based instruction of three teachers toward the goal of identifying teaching practices and instructional contexts that result in rich scientific literacy learning opportunities for upper elementary students. Specifically, this literature review will respond to three questions relevant to that purpose: (1) What is inquiry-based science instruction and how can curricular materials support teaching and learning that involves this approach to science instruction? (2) What is scientific literacy when viewed through a sociocognitive theoretical perspective that integrates a logic of inquiry that focuses on participant structures, connections to prior experiences, and support for argumentation skills? (3) What are the prior research findings from the program of research from which this study's data come?

Curriculum and Instruction in Inquiry-Based Science

Essential Features of Inquiry-Based Science Instruction

As already noted, inquiry-based instruction has been recommended (NRC, 1996, 2000, 2006) for supporting students in developing scientific literacy; and while this approach to science instruction can vary across settings, the *National Science Education Standards* (NRC, 1996) and the NRC document, *Inquiry and the National Science*

Education Standards (2000), identify specific distinguishing features of inquiry-based science instruction.

The content standards for science as inquiry specify that all students should develop both the abilities necessary to do scientific inquiry and understandings about scientific inquiry (NRC, 2000). The *Standards* further specify, as shown in Table 2.1, what those fundamental abilities and understandings are. The inquiry abilities identified require students to combine scientific processes with scientific knowledge instead of learning one in the absence of the other.

Table 2.1
K-4 Fundamental Abilities Necessary to Do Scientific Inquiry and Understandings about Scientific Inquiry

Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.
Scientists use different kinds of investigations depending on the questions they are trying to answer.
Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.
Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge).
Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.
Scientists review and ask questions about the results of other scientists' work.

Derived largely from the abilities to do scientific inquiry and the understandings about scientific inquiry, the NRC (1996, 2000) identifies five essential features of classroom inquiry, shown in Table 2.2, that apply across all grade levels. These features reflect Haury's (1993) identification of the search for knowledge and understanding as the heart of inquiry-based instruction.

Table 2.2
Essential Features of Classroom Inquiry

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.

These essential features do not oversimplify inquiry-based instruction as it is sometimes characterized by the terms “activity-based” or “hands-on.” Such terms suggest that the activities are themselves the goals of the inquiry approach to teaching (Bybee, 2004). Instead of defining inquiry-based instruction as emergent from the activities implemented, the NRC-identified essential features of classroom inquiry center on the learner’s mental activity, which is aimed at scientific explanation.

The NRC (2000) goes on to explain that classroom inquiries can be “full” or “partial.” While full inquiries include all five essential features of classroom inquiry identified in Table 2.2, a partial inquiry might, for example, begin with the assignment of an experiment instead of the engagement in a scientific question. Or a partial inquiry might include a teacher’s demonstration of how something works instead of instruction that involves students in exploring and developing their own questions or explanations.

The NRC (2000) also explains that inquiry-based instruction can vary in the amount of guidance a teacher provides with respect to any of the essential features. For example, engagement with a scientifically oriented question can range from learners posing the question to the learners engaging in teacher- or curriculum-provided questions. Likewise, the role of evidence in classroom inquiries can range widely. Learners may determine themselves what constitutes evidence and then collect it; or learners may be given data and be told how to analyze them. In this same way, the guidance teachers provide to students can vary for each of the features of classroom inquiry. The more responsibility that students have for directing the inquiry, the more "open" the inquiry is; and vice versa - as teachers take on more responsibility, the inquiry becomes more guided.

Finally, the NRC (2000) also lays out common, but not necessarily essential, components shared by instructional models that incorporate the features of classroom inquiry into a sequence of learning experiences. These components are shown in Table 2.3.

Table 2.3
Common Components Shared by Instructional Models for Classroom Inquiry

Phase 1: Engagement with a scientific question where students connect with what they already know.
Phase 2: Exploration of ideas through hands-on experiences, formulation and testing of hypotheses, solving problems and creating explanations.
Phase 3: Analysis and interpretation of data, synthesis of ideas, constructing of models and clarification of concepts and explanations.
Phase 4: Extension of new understanding and abilities to new situations.
Phase 5: Review and assessment of what was learned and how learning occurred.

While these components are not the defining and essential features of classroom inquiry, they are often observed in inquiry-based instructional models such as the 5E model (Bybee, 2004) whose sequence of *engagement, exploration, explanation, elaboration* and *evaluation* roughly follows the sequence shown in Table 3. Another example is the *Inquiry Cycle* described by White and Frederiksen (1998) whose sequence is a continuous circle of the following phases: *question, predict, experiment, model and apply*.

This section has shown that there are fundamental abilities necessary to do scientific inquiry and fundamental understandings about scientific inquiry. However, there is also a great deal of flexibility with regard to certain features of inquiry-based science instruction. Teachers can implement full or partial inquiry-based instruction that involves all or only certain features of typical inquiry-based science instruction. Teachers can also vary the amount of guidance they provide to learners. Finally, typical instructional models for inquiry-based science tend to involve students in five types of learning activities; but variation across these activities is certainly possible. Thus, there is no *one way* to implement inquiry-based science instruction; and the task of making broad recommendations for the successful implementation of inquiry-based science instruction is more complex than one might imagine. This dissertation study generates recommendations for the successful implementation of inquiry-based science instruction that utilizes three specific instructional modes. As a study of their enactment, it attends closely to variations within inquiry-based science instruction, particularly in the amount of guidance students are provided and in the particular learning activities that students engage in.

Trends in Curriculum Development

Given that research has indicated the effectiveness of inquiry-based science instruction in supporting students' development of scientific literacy, it could be argued that inquiry-based science curricula would be well-positioned to create change in school instruction and to engage more students in scientific literacy. But as Elmore (1996) noted, American schools frequently adopt new curricula; and nevertheless, instruction tends not to change dramatically. For example, Elmore reflected upon the National Science Foundation-sponsored curricula implemented during the 1950s and 1960s. The curricula integrated an inquiry approach and resembled the actual processes by which human beings come to understand their environment, culture and social settings. However, Elmore explained that these apparently innovative curricula were often "shoe-horned into old practices, and, in most secondary classrooms, the curricula had no impact on teaching and learning at all" (p. 13). One explanation for the limited effects of curricula on teaching and learning is that they often overlook the critical agent: the teacher (Ball & Cohen, 1996). Elmore's critique takes this shortcoming of the NSF-sponsored curricula into account. In contrast to traditional science instructional approaches of the time, where the object of study was the assimilation of facts, these curricula involved students in activities similar to serious practitioners of a discipline, including learning the methods and concepts of scientific inquiry. But while enormous resources went into the development of these curricula, they were criticized for embodying a naïve, discredited, and badly conceived model of how to influence teaching practice (Elmore, 1996):

> The model, if there was one, was that "good" curriculum and teaching practice were self-explanatory and self-implementing. Once teachers and school administrators recognized the clearly superior ideas embodied in the new curricula, they would simply switch from traditional textbooks to

> the new materials and change long-standing practices in order to improve their teaching and the chances of their students succeeding in school. (p. 13)

Clearly, this was not the case. Still today, inquiry-based science instruction proves difficult to implement.

Ball and Cohen (1996) argued that teachers must learn about curricula in order to implement them and that teachers will necessarily shape the curriculum as a function of their understanding of the material, their beliefs about what is important, and their ideas about students' and the teacher's roles. This shaping of the curriculum creates a gap between the *intended curriculum* (as intended by curriculum writers) and the *enacted curriculum* (as enacted by teachers). Ball and Cohen (1996) therefore argued that curriculum designers ought to attend more closely to the processes of curriculum enactment if the curricula are to contribute to professional practice.

Recent research reported by Brown and Edelson (2003) and by Remillard (1999, 2000, 2005) has served to develop a more finely nuanced understanding of why there is a gap between intended and enacted curricula. Like Ball and Cohen, these researchers also acknowledge the critical role that teachers play in curriculum enactment. For example, Brown and Edelson (2003) reported on a study that explored the way that three urban middle school science teachers interacted with curriculum materials for a unit on global warming. The study pointed to the differential ways that teachers interacted with varied aspects of the curricular materials in light of their unique knowledge, skills and commitments. The findings led the authors to argue that teacher practice is a design activity. They explained, "Teachers must perceive and interpret existing resources, evaluate the constraints of the classroom setting, balance tradeoffs and devise strategies –

all in the pursuit of their instructional goals. These are all characteristics of design" (p. 1). The authors advocated a notion of teaching as design that highlights three key points: (a) curriculum materials play an important role in affording and constraining teachers' actions; (b) teachers notice and use such artifacts differently given their experience, intentions and abilities; and (c) teaching by design is not so much a conscious choice but an inevitable reality (p. 1).

One of the study's main findings was that teachers offloaded, adapted or improvised with curricular materials to varying extents in the performance of instructional tasks (Brown & Edelson, 2003). The authors characterized these degrees of distribution as lying along a spectrum where at one extreme, teachers offloaded responsibility for guiding instructional activity onto the curricular materials; and on the other extreme, teachers improvised their own strategies for instruction with minimal reliance on the materials. At the middle of the spectrum, adaptation of materials occurred when teacher actions reflected contributions of both the curricular materials and their own personal resources. These findings were integral to the development of the Design Capacity for Enactment Framework, which identifies and situates the curricular and personal resources that can influence how a teacher adapts, offloads or improvises with curriculum resources. Specifically, the authors identify three sources of curricular resources – procedures, domain representations and physical objects – and three sources of teacher resources – pedagogical content knowledge, subject matter, and goals or beliefs – as being integral in these interactions. One of the main implications of this work is that teachers possess unique pedagogical design capacities, or abilities to perceive and utilize existing resources in order to design instruction. The authors also argue that curricular materials should be designed to build upon these capacities.

Remillard (1999, 2000, 2005) also acknowledged the critical role of the teacher in curricular enactment. She builds upon Ben-Peretz's (1990) conception that there are two levels of curriculum development, one of which is largely shaped by teachers. The first level consists of what curriculum writers do when they conceptualize and write curricular plans. The second level consists of what teachers do as they adapt curricular materials to make them appropriate for their students. In this way, Remillard refers to teachers themselves as curriculum developers.

Remillard's (1999, 2000) case study research of two elementary school teachers examined their use of the same reform-oriented mathematics curriculum. These analyses revealed patterns in curriculum development activities and ultimately led to a model of the teachers' role in curriculum development. Remillard's model includes three arenas, the design arena, the construction arena, and the mapping arena, which each define a particular realm of the curriculum development process about which teachers explicitly or implicitly make different types of decisions:

> The design arena involves selecting and designing tasks for students. Here the teachers consulted and interacted with the textbook most explicitly. The construction arena involves enacting these tasks in the classroom and responding to students' encounters with them. Both teachers' activities in this realm of decision making tended to be improvised and responsive, involving in-action decisions. Thus, the text did not play a central role in this arena. The mapping arena involves making choices that determine the organization and content of the curriculum. Unlike the first two arenas, the mapping arena is not directly related to daily, classroom events; rather, it impacts and is impacted by them. (Remillard, 1999, p. 322)

Remillard acknowledged that the three arenas are not distinctively described to suggest that teachers make choices in serial or in isolated ways. Interrelationships among the three arenas exist; and furthermore, teachers demonstrate unique patterns with regard to their activities across and within the three arenas.

For example, in the design arena, one of the Remillard's case study teachers, Catherine, selected problem of the day tasks from the curricular materials that represented aspects of the curricular reform that she sought to add to her teaching. The other teacher, Jackie, did not select tasks from the curricular materials. Instead, she used the materials as a source of mathematical and representational ideas from which she adapted and invented her own tasks. Thus, Remillard's findings showed that two teachers *read* and appropriated the curriculum materials in very different ways. She explained, "Whereas Catherine's reading provided her with a set of activities to have students do, Jackie's reading resulted in a relationship or idea that she used to invent a task" (Remillard, 1999, p. 325). These contrasting uses of the curricular materials led to very different "enactments" and thus very different opportunities for learning for students. Remillard's research also showed that these differential approaches to reading the curricular materials were influenced by numerous factors, including the teachers' beliefs about the content and nature of mathematics, the curricular reforms, and learning. Also, though the teachers worked in the same district, professional development opportunities with regard to supporting teachers' use of the new materials were much more robust in Jackie's school.

Whereas activities that occur in the design arena are necessarily shaped by teacher actions, which s/he may determine based on the needs of students, activities that occur in the construction arena are necessarily shaped by all interactions in the classroom. Remillard (1999) explained that a central activity in the construction arena is task adaptation, where teachers adapt and adjust tasks in order to facilitate students' work with them. These adaptations are likely to become particularly complex and improvisational when instruction is aimed at making student thinking central and thus fosters unanticipated student ideas through which the teacher must navigate. Thus, the interrelationship between activities that occur in the design arena and the construction arena is critical. Remillard referred to teacher selection of tasks in the design arena as *seeds* for the paths that are determined by teachers' responses to students' interactions in the construction arena. Finally, these two arenas are situated within the mapping arena, which effectively determines attributes of instruction such as the content, sequence and timing of its topics.

In sum, Remillard's model shows just how complex the enactment of any curriculum can be. Teachers' interactions with curriculum materials are influenced not only by the curriculum development realms or "arenas" within which they act, but also by their own characteristics and the needs and actions of their students. Systematic study of the relations between teachers, students and curricular materials within each of these realms can offer insight into exactly how teachers can be supported in designing instruction. This orientation toward educational research may be most beneficial when examining instruction, such as inquiry-based science instruction, that attempts to position student thinking at the center of teaching and learning.

The above discussion has described inquiry-based science instruction and the role that curricular materials can potentially have in supporting this approach to instruction. The researchers described here have generated complex understandings of the teaching-learning relationship and have advocated approaches to curriculum development that more closely consider the role of the teacher in instruction. A commonality across their stances is that they propose a need for educative curricula that speak *to* the teacher instead of *through* the teacher (Remillard, 2000), such that teachers are not regarded as mere conduits to reach students. This dissertation study carefully examines the enactment of three curricular modes of inquiry-based science instruction and thereby generates understandings of a particularly complex form of instruction. Its findings thereby also generate understandings that can inform the development of educative curricula for inquiry-based science instruction.

Theoretical Perspective

Scientific Literacy: An Integration of Substantive and Syntactic Knowledge

In addition to the descriptions of inquiry-based science instruction and the role of curriculum development in supporting this type of instruction that I have already provided, it is also important to consider the specific way that scientific literacy is defined for the purposes of this study. This dissertation study examines the way that inquiry-based science instruction relies upon a definition of scientific literacy that considers both the substantive and syntactical knowledge integral to the scientific discipline (Schwab, 1962; 1964). Schwab (1964) recognized the critical role of the conceptual or substantive structures of a discipline:

> What questions we shall ask…the questions determine what data we wish; our wishes in this respect determine what experiments we perform. Further, the data, once assembled, are given their meaning and interpretations in light of the conception which initiated the inquiry. (p. 9)

However, Schwab argued that there are also major differences in the syntactical structures of unique disciplines, meaning that each discipline may implement unique practices for verifying its knowledge. Students should learn to engage in these different practices that are unique to a discipline.

> There is, then, the problem of determining for each discipline what it does by way of discovery and proof, what criteria it uses for measuring the quality of its data, how strictly it can apply its canons of evidence, and, in general, of determining the route or pathway by which the discipline moves from its raw data through a longer or shorter process of interpretation to its conclusions. (p. 14)

As I have noted already, throughout this dissertation study, I refer to these practices as scientific practices. Schwab (1962) criticized curricular attempts to apply methods or scientific practices in algorithmic ways that involved students in laboratory activities such as observation and data collection without interpretation, conclusion or discussion. He argued instead that science instruction should integrate syntactic and substantive knowledge by teaching the use of methods in service of concepts. In such a model, the learning of syntactic understandings would occur through authentic laboratory activities, where students realized the difficulty of data collection, experienced controlled exemplars of scientific inquiry, and participated in discussion about their experiences.

A Sociocognitive Perspective

The sociocognitive framework I use views school-based science learning as occurring in classroom communities in which enculturation and personal knowledge construction are intertwined (Driver, Asoko, Leach, Mortimer, & Scott, 1994). I regard teachers' roles as inducting students into the norms of science, but also rely on central ideas of cognition, such as metacognition and depth of processing of information through elaboration and synthesis (Hogan, Nastasi & Pressley, 1999).

This view of science learning as enculturation privileges the dialogic process that takes place between teachers and students during science instruction. The dialogic process is also central to Schwab's model of scientific inquiry that integrates the learning of substantive and syntactic knowledge through authentic inquiry. Teachers facilitate this process of enculturation by providing learners with access to physical experiences, concepts, and models of conventional science. But learners ultimately must learn to appropriate these models for themselves (Driver et al., 1994). Thus, the teacher's role is complex. Not only must teachers make the tools of science accessible, but they must also diagnose ways in which students are interpreting instructional activities in order to inform further instruction. Like conductors of an orchestra facilitate the construction of music, teachers facilitate students' knowledge construction. Teachers are in the critical, yet challenging, position to weave student voices together with shared and individual learning experiences and also with curricular texts. Through this dialogic process, teachers can provide students with opportunities for learning scientific literacy.

Thus, the theoretical perspective informing this dissertation study recognizes that learners must be enculturated into scientific literacy in a way that supports them in developing both substantive and syntactical knowledge structures. Knowledge of scientific concepts is not useful in the absence of an understanding of the process that generated those understandings; and knowledge of practices central to a discipline is not useful in the absence of an understanding of the concepts those practices can help to generate. Furthermore, acquiring scientific literacy in a way that integrates these substantive and syntactical knowledge structures requires a method of instruction that integrates social and cognitive paradigms, thus enculturating learners into a way of thinking.

Logic of Inquiry

I have discussed the foundation for what can be expected of inquiry-based science instruction, in terms of basic features of classroom inquiry and in terms of common components of instructional models for classroom inquiry. But as also noted, there may be large variation in different enactments of inquiry-based science instruction. The following discussion reviews several examples of programs of research that have investigated whether and how inquiry-based science instruction can be more effective when the following aspects of instruction are manipulated: participant structures, connections with prior experiences, and argumentation. These three aspects of instruction also direct this dissertation study's logic of inquiry. My review of the literature in science education in hand with my initial viewing of the study's data corpus during a pilot study suggested to me that these three lenses would be particularly useful for guiding the analyses in my study. In other words, this study involved a logic of inquiry that incorporated three analytical lenses, each of which were directed at uncovering opportunities for learning that arose as a function of participant structures, connections to prior experiences, or argumentation. As will be described in greater detail in Chapter 3, the study examines these aspects of instruction nested within modal differences of one curricular approach to inquiry-based science instruction.

In the following sections, I first describe the role that each lens has played in educational research on inquiry-based science instruction. I also elaborate on the specific terminologies that I rely upon in describing my findings. In Chapter 3, I reference these three lenses again and explicitly describe the way that they were integrated into my analytical methods.

Participant Structure

Many studies have attended to the complexity of inquiry-based science instruction by examining and manipulating participant structures in classroom dialogue. Hogan and Corey (2001) reported on the challenges they faced in implementing inquiry-based science instruction due to the traditional participant structures of schooling and their inherent conflict with the collective nature of science. For example, when the teacher-researchers attempted to engage students in the scientific process of peer review, one student provided negative criticism only and resisted providing any constructive criticism. Similarly, when the teacher-researchers guided students in collaboratively designing a controlled experiment, students voiced a preference to work alone and not be held accountable to one another. They argued that they could not trust their peers to carry out procedures competently. Based on such students' responses, the authors argued that teachers and researchers must attend to the composite culture that shapes students' experiences of science, in terms of their contextual resources, interactive norms, and school-based cultural perspective. In other words, while there may be numerous benefits to the non-traditional participant structures that may be supported by inquiry-based science instruction, teachers must also be prepared for the challenges they will meet in guiding students to adopt those non-traditional participant structures.

In response to issues such as these, several studies, including the work of Herrenkohl and colleagues, have manipulated and examined participant structures within inquiry-based science instruction. For example, Herrenkohl and Guerra (1998) found that assigning roles to fourth grade participants as they reported their findings (reporters) to an audience of their classmates (audience) as well as providing roles to the audience encouraged a higher level of engagement across students as compared to their counterparts where only reporters received role assignments. The roles required students to either report or listen for 1) predicting and theorizing; 2) summarizing; or 3) relating predictions, theories and results. Audience members were also supported in asking for clarification when they did not understand the reporter or felt the reporter was incomplete. The authors argued that the alternative participant structures led to a focus on understanding, clarifying, and sharing meaning instead of a focus on findings alone. The authors also found that teacher roles were affected by the student roles. In the intervention setting where only reporters were assigned roles, teachers tended to initiate more discussion around coordinating theories and evidence. But when both reporters and audience members were assigned roles, teachers attended more to monitoring comprehension and negotiating understanding. Students similarly tended to attend more to negotiating shared understanding and monitoring comprehension. In other words, a context where both reporters and audience members were assigned roles seemed to facilitate a classroom community of distributed cognition and expertise.

In a related study, Herrenkohl, Palincsar, DeWater and Kawasaki (1999) found that students in a 3rd/4th grade gifted urban classroom and students in a 5th grade urban classroom developed improved conceptual understanding and use of intellectual scientific tools and thinking strategies when they participated in classroom discussions where reporters and audience members were assigned discussion roles. Like the study conducted by Herrenkohl and Guerra (1998), students were assigned rules around the tasks of predicting and theorizing, summarizing results, and in comparing predictions and theories to results. The findings from the study showed changes both in the students' conceptual understandings and in their scientific practices. Prior to the intervention, only 3.7% and 0% of the students in the 3rd/4th grade and 5th grade classes respectively used a density rationale to explain why objects would sink or float. These proportions increased to 62.96% and 47.83% respectively after the intervention. The study also reported findings related to the students' practices. For example, a "theory chart," in which students tracked proposed theories as they evolved, helped students to participate in science as revision. In contrast, prior to the intervention, students tended to consider theories as "fixed" entities; but the intervention supported their learning that theories could be changed when evidence points in a new direction.

In another study that examined participant structures in inquiry-based science instruction, Tabak and Baumgartner (2004) argued for a structure they name the *partner participant structure,* which is marked by a symmetrical relationship between teachers and students. The authors explained that inquiry-based science instruction has the potential to nurture this type of a participant structure:

> In inquiry-based science classrooms, the student-directed, first-hand investigations form the hub of activity and the locus of knowledge construction. Teachers may be proficient in the practice of science, but the student groups are more versed in the content and details of their specific projects or investigations. This twist has the potential to imbue students with some of the power traditionally held by the teacher, which, as we have noted, has been shown to carry positive pedagogical power. (p. 400)

The authors provided an example showing that a student appeals to the data to defend his position in contrast to his teacher's position. Thus the "last word" can be either his or the teacher's, whereas teachers would traditionally have the institutional authority to determine the correct answer. This facet of inquiry-based instruction potentially positions students as scientifically knowledgeable, thus allowing them to perceive of themselves as able-minded scientists and knowledge-creators.

These studies demonstrate that manipulating and attending to the participant structures of classroom discussion can help to negotiate the complexity of inquiry-based science instruction. In fact, manipulating this aspect of instruction can lead to improved outcomes. They also show that students can be enculturated into scientific communities where conversation, collaboration and shared meaning making are central tenets to science learning. One study has even shown that inquiry-based science instruction has the potential to empower students by positioning them as classroom experts when it comes to their own data (Tabak & Baumgartner, 2004).

However, there are also challenges associated with implementing inquiry-based science instruction. I have already discussed the challenges associated with changing traditional science instruction and the way that these challenges may result from the high demand for resources associated with inquiry-based instruction. While the research literature has shown that inquiry-based science instruction can indeed benefit learners by positioning them in ways that they participate in meaningful learning, it has not demonstrated how varied participant structures emerge when trying to address the challenges of inquiry-based science instruction. This dissertation study closely examines the enactment of three instructional modes of inquiry-based science instruction, thereby uncovering both productive and unproductive participant structures that can emerge when teachers and students address the real challenges of inquiry.

In addition to informing the study's analytical focus on the relationship between participant structures and the learning opportunities that developed, several studies influenced the terminologies that I used in conceptualizing and reporting my results. For example, I focused largely on the way that teachers used the revoicing strategy (O’Connor & Michaels, 1993), which generally consists of repeating a student contribution, to develop children’s learning opportunities for engaging in scientific practices and for acquiring accurate conceptual understandings. O’Connor and Michaels (1993) are largely credited with demonstrating how this discourse strategy can be used to position students in or out of alignment with conceptual propositions and to reformulate student propositions in ways that credit students with teachers’ warranted inferences. However, several other researchers have further developed understandings of how revoicing is used, particularly with young children and in inquiry settings. For example, Chapin, O’Connor and Anderson (2003) discussed the way that teachers can attempt to revoice children’s contributions when they are particularly unclear – both for the purpose of encouraging the student to clarify his/her meaning and for the purpose of enabling other learners to engage with the otherwise unclear proposition. In fact, the authors also showed how revoicing can be followed with discourse moves that prompt students to elaborate upon their initial comments or that prompt other students to respond to a student’s comment. When used in this way, revoicing and related discourse strategies greatly alter traditional classroom participant structures. They allow teachers to position children as knowledgeable individuals whose ideas are worthy of consideration.

Several other bodies of research have informed the way I have focused on revoicing and related discourse strategies that affect participant structures. Beck, McKeown, Sandora, Kucan and Worthy (1996) reported on the way that teachers used several discussion moves that were variations upon revoicing. Specifically, they distinguished between repeating, paraphrasing, and refining. Teachers tended to literally *repeat* student contributions in order to make those contributions more public. They *paraphrased* student contributions by rewording them without modifying their meaning. This also served to make student contributions more public. However, teachers sometimes *refined*, or made substantial modifications to student comments. This strategy served to integrate the students' ideas into discussion by clarifying them, focusing them in a particular direction, or by restating them using more sophisticated language. Palincsar, Magnusson and Hapgood (2001) also discussed the way that a teacher can revoice a student's claim by actually extending it and advancing its accuracy or using terminology that is consistent with the scientific register.

In addition to these specifications upon the revoicing strategy, Beck, McKeown, Hamilton and Kucan (1997) reported on the use of other discourse strategies. One of these discourse moves, *turning back*, has also informed my work. Like Chapin et al. (2003), these authors pointed to the benefit of "turning back" the responsibility to students to elaborate on or to connect their ideas with the ideas of other students. This discourse move encourages students to reason carefully about their ideas and to construct understanding of larger ideas from what may otherwise appear to be disparate understandings. Goldenberg (1992) also suggested that instructional conversations (Tharp & Gallimore, 1988; 1989) are characterized by connected discourse where succeeding utterances build upon and extend previous ones. Palincsar et al. (2001) have referred to this discourse strategy as "brokering" a conversation or "corralling" the class's thinking. These authors also described a productive instructional conversation where a fourth grade teacher of inquiry-based science encouraged students to express disagreement and skepticism. They argue that the dialectical process of professional science requires debate between members of the community, and that the instructional process of classroom science should parallel such dialogue.

Goldenberg's (1992) recommendations for the conduct of instructional conversations also refer to several elicitation techniques. For example, Goldenberg suggested that teachers can elicit extended student contributions by inviting students to expand (e.g., "Tell me more about that"), specifically requesting elaborations (e.g., "What do you mean?"), restating student contributions (e.g., "In other words"), and using pauses or wait time. Goldenberg argued that such discourse moves promote more complex language and expression. He also recommended that teachers elicit student bases for their positions. These types of moves are consistent with recommendations given by van Zee and Minstrell (1997) and by Hogan et al. (1999) to elicit further elaboration of student thinking, thus leading students to higher levels of reasoning and explanation.

Each of the pieces I have discussed here informed the way that I examined participant structures in my analyses. The teacher discourse strategies I have examined served to position students as individuals who have valuable contributions that can potentially offer opportunities for learning. Throughout this study, I was attentive to understanding how these alternative participant structures might develop, with particular attention to the way that teacher discourse strategies mediated this development.

Connections to Prior Experiences

In addition to manipulating participant structures, researchers have also attended to the discourse demands of inquiry-based science instruction, including building connections between students' prior experiences and the school discourse of science. Varelas, Pappas and colleagues have referred to children's references to other texts or experiences as *intertextuality* (Varelas & Pappas, 2006; Varelas, Pappas, & Rife, 2005). In a study of two urban first and second grade classrooms, Varelas and Pappas (2006) examined classroom discourse during read-alouds of six information books on the topics of states of matter that were integrated with hands-on explorations of related phenomena. The authors found that when teachers supported students to use both narrative and scientific language, while at the same time modeling scientific language, students began to use more scientific language themselves and negotiate their own scientific understandings. Along similar lines, Varelas et al. (2005) argued that teachers need to uncover and foreground children's prior experiences and understandings so that their tacit understandings become overt ways of meaning making (p. 162).

Ballenger (1997) came to similar findings in her work with 5th-8th grade Haitian students in an urban school system. In this study, teachers initiated "science talks" that involved students in discussing their experiences with scientific phenomena such as mold, metamorphosis and skin color. Analysis of the science talk transcripts revealed that the classroom discourse allowed for various genres of talk, such as storytelling and joking, that are typically not included in scientific classroom discourse. Ballenger argued that students were able to move into scientific genres because their ways of talking were not in stark contrast to science talk. For example, in a discussion about mold in the students' homes, science talk became confounded with personal moral content as students told stories about the associations between the cleanliness of their homes and mold growth. As the discussions evolved, students moved toward greater specificity in describing how they cleaned their homes to avoid mold – a move that is also characteristic of scientific discourse.

In their work with seventh grade students in an urban dual language immersion school, Moje and colleagues (Moje, Collazo, Carrillo, & Marx, 2001) concluded that teachers must support students in bringing together the different discourses of the discipline, the classroom, and their lives to create “third spaces” that allow for enhanced scientific learning. The researchers focused their analysis on the literate practices and teacher-student interactions of several students who had exhibited high or low participation in an air and water quality project. The analyses showed that connections between teacher and students experiences allowed for a more seamless merging of discourses, as compared to instances when the teacher maintained the position of science expert. An example of this occurred when the teacher engaged students in thinking about their practice of boiling water before drinking it in their native countries. The researchers also pointed out a problem with the curriculum materials, which were designed to call up students’ experiences. Despite this factor, the curriculum did not support the students in making connections between those experiences and science content; rather, they tended to be treated separately in what appeared more like language arts exercises.

The studies discussed here demonstrate that classroom instruction can facilitate students’ entrance into scientific discourse when their experiences outside of the science classroom are viewed as capital to build upon. In a manner that is responsive to Delpit’s (1995) concern that instruction should not replace, but rather build upon, students’ primary discourses, Magnusson and Palincsar (1995) explained this attribute of guided inquiry-based science instruction:

> Distinguishing guided inquiry from historical approaches to science education is the assumption that it is important to use whatever knowledge students have in the process of building new understandings and that the process of building scientific knowledge will be facilitated by having many opportunities for learners to discuss and compare their understandings with others. (p. 44)

Not only do Magnusson and Palincsar accept children's previous experiences at the table of science and literacy learning, but they embrace it: "…as children bring their own life experiences to the navigation, and raise their individual and joint questions, new bridges and roads are built, connecting what at one time appeared to be isolated places – disparate understandings" (p. 50).

Thus, the research clearly suggests that building upon student experiences is a productive practice for engaging students in scientific thinking and language. However, as noted already, features of inquiry-based science instruction can vary in a multitude of ways. Thus, prescribing one-size-fits all recommendations is a difficult thing to do. The way that teachers facilitate connections between inquiry experiences and children's other experiences may vary widely across settings. By closely examining the enactment of three instructional modes of inquiry-based science instruction, this dissertation study uncovers multiple ways that different teachers build upon student experiences across varied instructional modes. My analyses are informed by these studies in that they examine not only children's references to other experiences but the way that instruction can utilize these experiences as capital to build upon (Donovan & Bransford, 2005). Palincsar (1986) has referred to this characteristic of instruction as the "deft use of student ideas and linking of those ideas to new knowledge" (p. 96). Similarly, Goldenberg (1992) has recommended that instructional conversations aimed at engaging students in higher order thinking should "hook into" student background knowledge or provide students with pertinent background knowledge. Furthermore, that knowledge should then be woven into discussion. In my analyses, I have examined the way that such activities do or do not occur.

Argumentation

The practice of scientific argumentation lies at the heart of inquiry. Many studies have investigated the role of argumentation and how salient it should be in science education. Kuhn (1993) criticized the common paradigm for regarding scientific thinking as exploration, in contrast to regarding scientific thinking as argument. First, she pointed out that while young children can readily be described as naturally curious about the natural world, this natural inclination seems to become less common as children enter adolescence. Kuhn argued that, in fact, scientific thinking does not come naturally, nor do the skills for scientific thinking diminish over time. Instead, Kuhn suggests the alternative of *science as argument*, linking scientific thinking in children to scientific thinking in professional scientific communities. She explained, "Scientists are well aware that explicitly justified arguments are needed to convince the scientific community, and they become accustomed to thinking in such terms" (322). Within this paradigm, scientific thinking can be taught and found in older children, adolescents and adults.

Research has shown that, indeed, science instruction tends not to facilitate children's development of argument skills, particularly for younger students. For example, a study conducted by Newton and Newton (2000) found that British primary teachers' oral discourse was largely confined to developing vocabulary and descriptive understandings of scientific concepts. There was little evidence of discourse aimed at developing causal understanding. Other studies have investigated the effects of implementing instruction that is directly aimed at improving student argument skills. Osborne, Erduran, and Simon (2004) provided 12 teachers with long-term professional development in strategies for teaching argument. They studied the students of six of these teachers to determine if there was any improvement in the quality or quantity of student argument. The method of instruction generally entailed presenting the students with competing theories, in both social studies and science, and then supporting them in examining, discussing and evaluating the arguments. The authors utilized the Toulmin (TAP) argument pattern (TAP) to analyze student arguments. According to this framework, the elements of arguments are claims, data, warrants, and backings, where the warrant essentially relates the data to the claim. The study found that over time, students used more argumentative discourse that included claims or claims and grounds for those claims. However, the study also found that students used argumentative discourse significantly less in science lessons than in social studies lessons, suggesting that initiating argument in a scientific context is more demanding for students. The authors attribute this stronger ability to argue in a social studies context to the knowledge students have developed informally through their own life world experiences. In contrast, students must develop specific knowledge of scientific phenomena in order to become adept at evaluating scientific evidence.

Engle and Conant (2002) provided more specific pedagogical support for facilitating fifth grade students' participation in an emergent and sustained argument about a species' classification. Specifically, the authors reported that productive disciplinary engagement can be fostered when teachers design learning environments that support the following qualities: (a) problematizing subject matter; (b) giving students authority to address such problems; (c) holding students accountable to others and to shared disciplinary norms; and (d) providing students with relevant resources.

Within research in the area of argumentation, others programs of study, such as that conducted by Kuhn and colleagues, have investigated children's development of specific argument strategies including control of variables and multivariable prediction. Kuhn, Black, Keselman and Kaplan (2000) reported on middle school children's lean understandings of these strategies. The ability to make a prediction based on multiple variables requires an understanding that additive effects operate individually on a dependent variable but are cumulative or additive in their outcomes. Instead, students frequently believe that a variable makes a difference sometimes when the outcome is the desired result, but that the variable does not make a difference when the outcome is not the desired result. The authors refer to this mental model as the co-occurrence model, where a variable level or value is implicated as causal instead of a variable itself. This leads students to attribute causation based upon particular constellations of variable levels instead of variables altogether. The authors found, however, that given long-term and concentrated practice in developing these skills, students can develop the skills to develop correct mental models of multivariable causality where effects of individual features on an outcome are consistent and additive.

Kuhn (2007) investigated similar competencies in fourth grade students. Before implementing an intervention that gave students practice in developing the control of variables strategy, students tended to investigate the effects of multiple factors simultaneously and draw invalid inferences based on evidence that was compatible with theoretical expectation. An intervention providing long-term practice in developing the control of variables strategy did help students become proficient in designing controlled experiments to isolate effects of individual variables; but they were still challenged in making predictions involving multiple variables whose individual effects they had already determined. Instead, students had a tendency to shift the explanatory burden in a multivariable context from one single variable to another single variable, even when they were told specifically that they could implicate more than one variable.

Other studies have more directly reported upon pedagogical recommendations for developing children's understanding of the control of variables strategy. Klahr and Nigam (2004), for example, studied third and fourth grade children's development of the control of variables strategy across direct instruction and discovery learning teaching approaches. Both approaches involved children in actively manipulating materials to investigate the motion of balls made of varied materials as they traveled down ramps of varied steepness and varied surfaces. However, in the direct instruction approach teachers provided more guidance by providing good and bad examples of the control of variables strategy, explaining what the differences between them were and telling students how and why the control of variables strategy worked. The authors found that many more children developed proficiency in the control of variables strategy from direct instruction than from discovery learning. In addition, children who had mastered the control of variables strategy from either teaching approach could transfer their skills to a new context where they were asked to judge other students' science projects.

The programs of research described here point to the need to develop pedagogical approaches that support children in developing argumentation skills. Despite the fact that argument is the backbone of the scientific domain, general and specific skills for argumentation tend not to be the focus of science instruction. In particular, research has shown that even when children develop skill in the control of variables strategy, they are still challenged with respect to making claims that take into account the effects of multiple variables (Kuhn, 2007). This dissertation study uncovers specific pedagogical approaches for supporting children in developing specific argumentation skills. By closely examining the enactment of three instructional modes of inquiry-based science instruction, this dissertation study uncovers both more and less productive ways that teachers have supported students in developing these important skills.

In reporting the findings of my analyses, I borrow terminology from Osborne et al. (2004) and Palincsar et al. (2001) to discuss the scientific arguments that children make. According to the Toulmin (TAP) argument pattern which was used as a framework by Osborne et al. (2004), the elements of arguments are claims, data, warrants, and backings, where the warrant essentially relates the data to the claim. Palincsar et al. (2001) similarly explained that a key feature of guided inquiry-based science instruction is determining what counts as evidence in a scientific investigation. Furthermore, children should critically examine the relationship between this evidence and the claims the evidence supports, refutes, or calls into question. My analyses also focus on the way that children use data as evidence to support, refute or call claims into question.

As I have also described, Kuhn and colleagues (Kuhn, 2007; Kuhn, Black, Keselman, & Kaplan, 2000) have investigated children's development of specific argument strategies including control of variables and multivariable prediction. These specific strategies are very relevant to this dissertation study. In my analyses, I focus on the way that opportunities for engaging in these two scientific argumentation skills were mediated. Specifically, I aimed to uncover the circumstances that supported children in developing these skills in service of accurate and complete conceptual understandings.

Prior Research Findings on GIsML Instruction

Finally, I also provide here a summary of prior research findings from the Guided Inquiry supporting Multiple Literacies (GIsML) program of research, which provide the data for this dissertation study. This body of research includes studies that implemented the use of a nontraditional science text that the researchers refer to as “a notebook text,” as it is meant to connote a scientist’s notebook. These texts were created as a means to engage children in second-hand investigations, the investigations of a fictitious scientist, Lesley Park. I will further elaborate upon the features of this research program, specific features of the notebook text, and their roles in this dissertation study in Chapter 3. However, I provide a brief summary of relevant empirical findings from the GIsML program of research here.

The GIsML program of research includes quasi-experimental research (Palincsar and Magnusson, 2001) that involved a within-subject, across-group study in which fourth grade children in seven classrooms served as their own controls by reading both a notebook text and a traditional version of a text. Both versions of the text addressed the general topic of light; but there were versions of each text type that addressed the subtopic of reflection and of refraction. Children who read the notebook version about reflection read the traditional version about refraction; and children who read the notebook version about refraction read the traditional version about reflection. The study found that in three of four samples, the notebook texts were more effective than traditional texts in improving students’ scientific understandings as demonstrated on assessments of syntactic and substantive knowledge; and in only one sample, for one topic (reflection), there were no significant differences between the outcomes for students who learned about reflection using the notebook text versus the traditional text. Thus, generally speaking, this research suggested an advantage in favor of learning from notebook texts over traditional texts.

These findings suggest a need to closely examine the nature of the instructional interactions supported by the two text types. While some GIsML research has begun to examine these interactions, close analyses of extended GIsML instruction would be greatly beneficial to developing a better understanding of instructional contexts that foster learning. At least preliminarily, descriptive studies suggested that when instruction featured the GIsML approach to inquiry-based science instruction, whether children were engaged in either first-hand investigation or in second-hand investigations using the notebook texts\, they were supported in engaging in the inquiry process. This was evident not only in children's development of scientific concepts but also in their engagement in scientific reasoning, adopting a critical stance toward text, and in metacognitive activity (Magnusson & Palincsar, 2004; Palincsar & Magnusson, 2001).

The GIsML body of research has also demonstrated that an interplay condition, which involved children in alternation between first-hand investigation and second-hand investigation using the notebook text, is most advantageous when students engage in first-hand investigations *before* second-hand investigations. The authors explain that this sequence allowed for second-hand investigations to be conducted in service of the first-hand investigation, thus placing student thinking at the forefront: "...the students' ideas were touchstones, not to be usurped by the text" (Palincsar and Magnusson, 2001).

Situating this Study

The GIsML studies reviewed here demonstrate the effectiveness of GIsML instruction. However, it is not clear what exactly leads to this increased achievement, and there have been no studies investigating GIsML instruction closely. As discussed already, numerous studies support the effectiveness of inquiry-based science instruction (NRC, 1996; 2000; 2006). But this type of instruction poses numerous challenges for teachers (DeBoer, 2004), thus inhibiting its broad implementation. Indeed, across disciplines, teachers tend to be the center of attention in classrooms (Elmore, 1995), a finding that is likely explained by the high demands upon teachers in inquiry-based inquiry instruction relative to the didactic alternative (Shulman, 1987). Cohen (1989) elegantly described these high demands as follows:

> …teachers must take on a large agenda: help students abandon the safety of rote learning, instruct them in framing and testing hypotheses, and build a climate of tolerance for others' ideas and a curiosity about unusual answers, among other things. Teachers who take this path must work harder, concentrate more, and embrace larger pedagogical responsibilities than if they only assigned text chapters and seat work. They also must have unusual knowledge and skills. They require, for instance, a deep understanding of the material and modes of discourse about it. They must be able to comprehend students' thinking, their interpretations of problems, their mistakes, and their puzzles. And, when they cannot comprehend, they must have the capacity to probe thoughtfully and tactfully. (p. 75)

With these concerns in mind, the GIsML program of research can contribute to the needs of the science education community in multiple ways. First, it provides three curricular modes of instruction (first-hand investigation, second-hand investigation and interplay of first- and second-hand investigations) for implementing inquiry-based science instruction that have proven effective for learning outcomes. However, these curricular approaches alone may not be helpful to practitioners who are aware of the demanding nature of teaching inquiry. The research base on GIsML instruction, and on inquiry-based science instruction as a whole, is lacking an understanding of the specific learning opportunities afforded by the three modes of guided inquiry instruction and how teachers can facilitate the provision of these learning opportunities. For the practitioner who wants to do what is best for her students, knowing that inquiry-based models *are recommended* is not enough. A finer understanding of *how* inquiry-based science instruction can be implemented *through* curricular approaches and *by* teachers is seriously called for. The proposed study will contribute to this need.

My study addresses a critical gap in the literature. Very few studies have investigated successful enactment of inquiry-based science teaching; hence, curriculum developers have little to turn to when trying to design educative curricula (Ball & Cohen, 1996; Cohen & Ball, 1999; Davis & Krajcik, 2005) that will support teachers in this form of instruction. This is a critical need, given the research indicating that enactments of inquiry-based science curricula are rarely congruent with practices as instantiated in curriculum materials (Hammer, 1997; Schneider, Krajcik, & Blumenfeld, 2005) and that enactments of the same curricula by different teachers can vary widely (Brown & Edelson, 2003; Puntambekar et al., 2007; Remillard, 1999; 2000). Rather, enactment models take into account the dynamism between teachers, students and curriculum materials – where each necessarily affects the others (Ball & Cohen, 1996; Cohen & Ball, 1999). Thus, understanding how teachers enact materials is critical to creating effective curricula (Schneider et al., 2005). Educational researchers must address this issue by conducting close examinations of varied curricula that illuminate the nuanced skills teachers must have in order to implement high-quality inquiry-based science instruction.

Thus, this study is responsive to these calls. It involved a high-quality detailed analysis of the inquiry-based science instruction of three teachers for the purpose of identifying teaching approaches and practices that result in rich scientific literacy learning opportunities for upper elementary students. My findings have implications for teacher education, curricular design, and for educational reform. They offer research-based insights that will allow teacher educators to provide preservice teachers with the knowledge necessary for implementing high-quality science instruction.

CHAPTER 3: METHODS

Overview

As already noted, this study investigates the way that children acquire the knowledge of scientific literacy, both syntactic and substantive knowledge, through three modes of guided inquiry science instruction. The specific research questions are the following:

1. *What are the differential opportunities students have to engage with scientific practices and to acquire accurate conceptual understandings in a first-hand, second-hand or first-hand followed by second-hand investigation?*
2. *What mediates the learning opportunities for engaging with scientific practices and acquiring accurate conceptual understandings across and within conditions?*

In this chapter, I describe the context of the study with regard to the GIsML program of research and its integral features. I then describe the study's data sources and the two phases of analytical methods I utilized.

Study Context: The *Guided Inquiry supporting Multiple Literacies (GIsML)* Program of Research

History

This dissertation study is situated within a larger program of research entitled "Guided Inquiry supporting Multiple Literacies" (GIsML). Thus, in the next section, I describe GIsML and the critical features of science instruction implemented through this program of research. The GIsML research program provides a suitable context for examining many of the issues described in Chapter 2. The program is referred to as

GIsML for the following reasons: “Inquiry” reflects the belief that inquiring is fundamental to learning; “Multiple literacies” reflects the notion that meaningful inquiry often crosses disciplinary boundaries and that it can support diverse forms of representation and ways of meaning making; “Guided” reflects the belief that the teacher plays a critical role in facilitating the development of scientific knowledge in an inquiry-based environment (Magnusson & Palincsar, 1995; Palincsar, Magnusson, Marano, Ford & Brown, 1998).

It may be useful to know that the GIsML research program first came to being in 1996 as a K-5 teacher professional development program. Teachers joined the project for the purpose of learning how to effectively teach science from a guided inquiry perspective (Palincsar et al., 1998). This professional development context, referred to as the *GIsML Community of Practice,* is important because it afforded the opportunity to conduct research informed by the experience of the teachers engaged in the project. However, while the GIsML Community of Practice has since dispersed, the GIsML research program has maintained its focus on guided inquiry-based science instruction.

Features of GIsML Instruction

A few features of guided inquiry instruction, as framed by GIsML researchers are important to note here. First, GIsML instruction can incorporate either first-hand or second-hand investigation. GIsML research has also investigated the interplay of first- and second-hand investigation, where students experience both modes of instruction.

The GIsML approach to instruction featuring first-hand investigation involves students in directly manipulating scientific phenomena, collecting and reporting data, and using these data to make knowledge claims. The GIsML approach to instruction featuring second-hand investigation is unique in many ways. First, the rationale for this mode of instruction, where students interact with written text to read what others have claimed regarding the nature of the physical world, is multifold. Numerous challenges are associated with traditional scientific text-based reading. Bean (2000) explained that when reading in the content areas, textbooks have traditionally been viewed as a means for conveying facts in a transmission style instructional approach. This has led children to view textbooks as boring, often complaining that reading them is a form of forced labor. Even within inquiry-based instructional contexts that are not dominated by a transmission style regime, Magnusson and Palincsar (2004) explained that text-based learning is typically seen to be at odds with inquiry-based learning. They cite problems with typical texts such as their emphasis on presentation and not on discovery, their density of information with little attention to explanation, and lack of cohesion as particularly problematic features of typical science texts.

Issues such as these have led scholars such as Wade and Moje (2000) to advocate participatory approaches to utilizing text. Such approaches allow students to make their own interpretations of texts and thus generate their own knowledge. Remillard (2005) also refers to participatory approaches with curricular texts between teachers and curricular materials. This perspective is based on the assumption that teachers and curriculum materials are engaged in a dynamic interrelationship that involves participation on the parts of both the teacher and the text. In response to these issues, GIsML researchers have designed nontraditional science texts that support participatory approaches to using curricular texts. The researchers refer to the text as “a notebook text," as it is meant to connote the notebook of a fictitious scientist, Lesley Park. Hapgood, Magnusson, and Palincsar (2004) described the notebook texts as following:

> The innovative texts that we have been designing and investigating are a hybrid of exposition, narration, description, and argumentation. In many respects, notebook texts represent a think-aloud on the part of a fictitious scientist, Lesley, who documents the purpose of her investigation, the question(s) guiding her inquiry, the investigation procedures in which she is engaged, the ways in which she is gathering and choosing to represent her data, the claims emerging from her work, the relations among these claims and her evidence, the conclusions she is deriving, and the new questions that are emerging from her inquiry. (p. 460).

These texts were created as a means to engage children in second-hand investigations. But they offer numerous teaching and learning affordances, as they provide a shared context for discussion of how a testable question can be derived from an observation of something intriguing in the world, examination of multiple forms of representations of data as well as of experimental setups, examination of a common data set with which to make knowledge claims, and discussion of the reasoning another person (Lesley) used while engaging in inquiry (Hapgood et al., 2004, p. 497). The affordances of the notebook text may also speak to concerns raised by researchers such as Hogan and Corey (2001) and Schwartz (2004) as they provide students with an opportunity to observe the scientific process a (fictitious) scientist engages in, thus exposing students to the culture of scientific communities despite their own contrasting composite cultures.

Thus, it should be noted that the notebook texts used in GIsML instruction are unlike traditional science texts in many ways. Most importantly, unlike traditional models of text-based science instruction, the GIsML curricular approach to using the notebook texts engages students in inquiry-based science instruction by involving them in second-hand investigations. However, it should also be noted that whereas second-hand investigations incorporating the notebook texts exhibit more similarity to first-hand investigation experiences than traditional informational text, there are important differences in the affordances and constraints of each mode of investigation (first- versus second-hand). Table 3.1 presents the affordances and constraints that Palincsar and Magnusson (2006) have hypothesized to be attributes of each mode of investigation. However, these attributes are only hypothetically put forth by the authors, and further research is needed to substantiate these descriptions.

Table 3.1.
Comparison of the Attributes of Different Modes of Instruction Featuring First-hand or Second-hand Investigation. (*Note.* From Palincsar & Magnusson, 2006)

	Affordances	Constraints
First-hand	Direct experiences can be powerful in concretizing scientific relationships describing the physical world.	• Variations in the data (due to the complexities of the real world and the many possible sources of error) increase the challenge of seeing patterns in the data • Students may make sense of their experiences in quite different ways from scientists.
	Direct experiences in which one manipulates the physical world, are powerful means for trying out and testing one's thinking.	• The social and physical demands of first-hand investigations (e.g., coordinating thinking and activity within a group, coordinating an array of materials) leave little room for students to focus conceptually, requiring additional time for conceptual invention to make meaning of what occurred. • Students may lose sight of the targeted question and become more engaged in pursing their own questions.
	Collaborating to produce knowledge claims is an important part of scientific activity.	Children's independent inquiry is not automatically guided by the cultural values, beliefs, norms, and conventions of the scientific community (e.g., need for adequate evidence, role of disconfirming evidence in revising thinking). Thus, students' claims might be quite contrary to the claims developed by scientists, sometimes across years of study.
Second-hand	A common set of pertinent information for the doing of science – question, method, data, knowledge claims – is presented to all children.	Interpretation of the information represented in static terms is required, and children's interpretations in the face of static presentation may be erroneous. The static nature of the information in the text may constrain children's abilities to employ the type of reasoning illustrated, when they inquire on their own.
	The processes of thinking that produce scientific knowledge are "laid bare," serving as a model for one's own thinking during scientific investigation.	The process of scientific reasoning is embedded within a context and particular conceptual ideas; thus, it is not transparent, and teacher guidance is required to help students identify and evaluate the scientific reasoning and decision making modeled in the text.

Table 3.1 specifies the relative hypothesized affordances and constraints of each mode of investigation in detail. But broadly speaking, a critical affordance of the first-hand investigation instructional mode is that in involves students in direct experiences with scientific inquiry. These experiences may be critical in helping children to test their ideas and construct their own scientific understandings. In addition, children have opportunities to engage in inquiry collaboratively, an opportunity that parallels the activity of the professional science community.

The affordances of the second-hand investigation instructional mode address some of the constraints of the first-hand investigation instructional mode, although it is also not without hypothesized constraints. First, the notebook text used in this instructional mode offers a common set of pertinent information for students, including reliable data, for students to work from, such that they are not distracted by data variation or unreliable data that they may collect themselves. Still, it could be argued that this is actually a constraint of the second-hand investigation instructional mode, as children do not personally experience all the real challenges associated with conducting scientific inquiry. In other words, there may be important benefits associated with learning to conduct investigations in ways that achieve reliable data. It may also be important for students to have opportunities to notice and address unreliable data when they do indeed result from one’s investigation. The other hypothesized affordance of the second-hand investigation instructional mode is one that I have already referred to in the preceding discussion. Following Lesley’s thinking in the notebook text offers children an opportunity to learn about the scientific practices of the professional science community, an experience that may be particularly valuable if students’ own experiences are dissonant with those of professional scientists. Still, Palincsar and Magnusson (2006) acknowledge that this affordance may not be transparent to young learners. Teachers will need to support students in identifying these practices themselves.

Thus, it becomes clear that both GIsML instructional modes, that featuring first-hand investigation or second-hand investigation, offer potential affordances and constraints for learning. The interplay condition could hypothetically offer the best (and worst) of both worlds. But such a hypothesis has also not been proven.

A final feature of GIsML instruction that merits mention here is that it has three main phases: *Engage, Investigate,* and *Report,* with two supporting phases – *Prepare to Investigate* and *Prepare to Report*. These phases are visually presented in the GIsML Heuristic Diagram shown in Appendix A. Regardless of mode of instruction (first-hand investigation, second-hand investigation or an interplay of first- and second-hand investigation), these phases can be characterized similarly (Magnusson, Palincsar & Templin, 2004); however, in first-hand investigations students experience the phases themselves, and in second-hand investigations they read about Lesley's experience in each of the phases. Each cycle begins with engagement around a question regarding a real world phenomenon. Children are supported to express wonderings about the physical world in response to the guiding question and to consider their relevant prior knowledge and experience. This is followed by preparation to investigate, which typically involves deriving a testable question, modeling of the phenomenon and preparation of the investigative setup. During the *Investigate* phase, data is collected and represented (in tables or other representations). The *Investigate* phase is followed by preparation to report, which involves the brainstorming of claims based on the evidence that was collected. Finally, a cycle ends with the public reporting and evaluating of those claims and their associated evidence. The heuristic (see Appendix A) also makes these focal issues of each phase of instruction salient. During any one unit of instruction, students repeatedly cycle through these same phases recursively, such that they experience multiple opportunities for learning. It is significant to note that only one of the phases, *Investigate*, is dominated by physical activity, while the other phases are largely dominated by conversation. This emphasis is one that is consistent with current understandings of scientific knowledge production (Magnusson et al., 2004) in that it emphasizes the dialogic nature of knowledge production and the language demands inherent to this process.

Design and Methodology

Program of Research

This study utilizes data collected through the GIsML program of research through a study entitled, *The influence of first- and second-hand investigations on learning opportunities and outcomes in inquiry-based science in the elementary school*[1]. This program of research included the enactment and study of guided inquiry science instruction in which three senior research team members, Ms. Allen. Ms. Baker and Mr. Cannon, conducted all instruction for six groups of 4th grade children (n = 7, 8, or 9 per group). The names used for all participants in this study, including teachers and students, are pseudonyms. As already described, this program of research involved the use of an innovative notebook text that supported second-hand investigation in conjunction with an inquiry approach to science instruction. The topics of instruction covered in first-hand

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[1] This study was supported by a Research on Learning and Education (ROLE) grant awarded to co-PIs, Palincsar and Magnusson, from the National Science Foundation from 2002 to 2005.

investigations and in the notebook texts were motion across a horizontal plane and motion on an inclined plane, with one week of instruction allocated for each topic of study.

Site of Study and Participants

The site of the study was a rural school in Southeast Michigan, and the children that participated in the study were fourth graders in October and November 2003 when the data were collected. The children were divided into six small groups (total n= 50; n=7, 8 or 9 per group) for all instructional activities over the duration of two weeks. They were instructed in small groups in order to maximize the researchers' ability to study individual conceptual development.

As already noted, an important finding from the series of studies conducted as part of this program of research is that it was most advantageous for students to engage in first-hand investigations *before* second-hand investigations (Palincsar and Magnusson, 2001). Because of this critical finding, the interplay condition in this study only involved students in first-hand investigations before second-hand investigations. Thus, children in condition 1 experienced two weeks of first-hand investigation while studying both topics of study, children in condition 2 experienced two weeks of second-hand investigation while studying both topics of study, and children in Condition 3 experienced one week of first-hand investigation while studying motion across a horizontal plane followed by one week of second-hand investigation while studying motion down an inclined plane.

Student assignment to the conditions was based upon the results of two assessments: the Gates-MacGinite reading test and a prior knowledge multiple-choice assessment that included both content items and reasoning items. The knowledge assessments are included in Appendices B and C. The Gates-MacGinite served as a proxy for school achievement and was thus used to control for general school achievement. The prior knowledge assessment was used to control for specific knowledge relevant to the topics of study addressed by instruction in this research study. The study used stratified random assignment, controlling for school achievement (using the Gates-MacGinite) and children's entering knowledge specific to the topic of study (the knowledge assessment). Students were categorized into low, medium, and high levels of general achievement and were then matched on achievement and prior content knowledge and randomly assigned to one of the three conditions: the first-hand investigation condition, the second-hand investigation condition, or the interplay condition. Comparison of reading assessment performance and prior content knowledge revealed no significant differences among the three conditions or six instructional groups (two instructional groups in each condition).

Table 3.2 shows the teachers and size of the two instructional groups per condition. For the first-hand investigation condition, Ms. Baker instructed one group (n=9), and Mr. Cannon (n=9) instructed one group. For the second-hand investigation condition, Ms. Baker instructed one group (n=7), and Ms. Allen (n=9) instructed one group. For the interplay condition, Ms. Allen (n=8) instructed one group, and Mr. Cannon (n=8) instructed one group. An effort was made to insure that every instructional group had an almost equal number of students. However logistical issues such as school and classroom schedules also affected the numbers of students placed in each group.

Table 3.2
Teachers and Size of Each Instructional Group

First-hand investigation instructional groups	Second-hand investigation instructional groups	Interplay instructional groups
Ms. Baker (n=9)	Ms. Baker (n=7)	Ms. Allen (n=8)
Mr. Cannon (n=9)	Ms. Allen (n=9)	Mr. Cannon (n=8)

Gain Scores

The knowledge assessment was readministered at the end of the study; however, this dissertation study did not involve a secondary analysis of those scores. Nevertheless, the gain scores provide a useful source of information that serves to situate this dissertation study.

Palincsar and Magnusson (2006) reported that gain scores for *content* items (see knowledge assessments in Appendices B and C) were highest for the first-hand investigation condition and lowest for the second-hand only condition, with the Interplay condition falling between the other two. In week one when students studied motion across a horizontal plane, the change in *reasoning* scores followed the opposite pattern from learning content. Gain scores were lowest for the first-hand investigation condition and highest for the second-hand investigation condition, with the interplay condition falling in-between. In week two when students studied motion down an inclined plane, students in the interplay condition showed the greatest gains while students in the second-hand investigation condition showed the least gains.

Due to the complexity of these outcome scores, Palincsar and Magnusson (2006) also considered individual student scores within condition. Figures 3.1, 3.2 and 3.3 show individual students' combined content and reasoning scores per condition. Orange lines show increases in understanding and blue lines show decreases in understanding, with different thicknesses representing different amounts of change: thin lines represent changes of less than 10%, lines of medium thickness represent changes of 10-20%, and the thickest lines are changes greater than 20%. The green lines represent no change, and the white line represents changes in the *mean* score for the group.

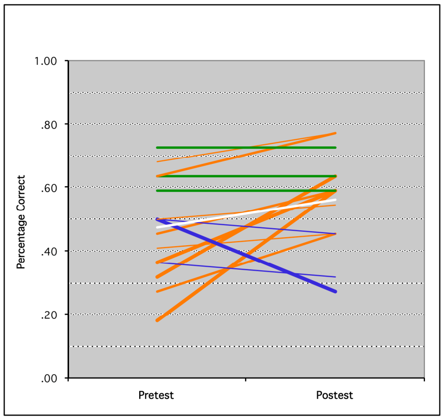

Figure 3.1. Changes in combined content and reasoning scores for individual students in First-hand investigation groups. (*Note.* From Palincsar & Magnusson, 2006)

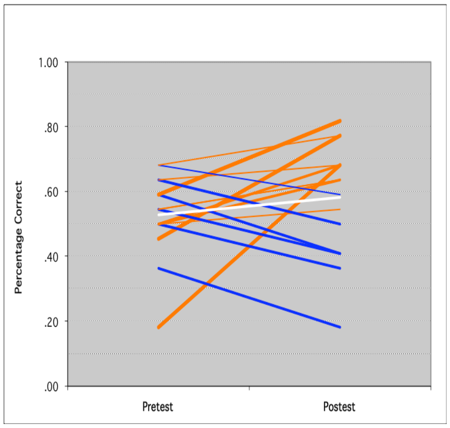

Figure 3.2. Changes in combined content and reasoning scores for individual students in second-hand investigation groups. (*Note.* From Palincsar & Magnusson, 2006)

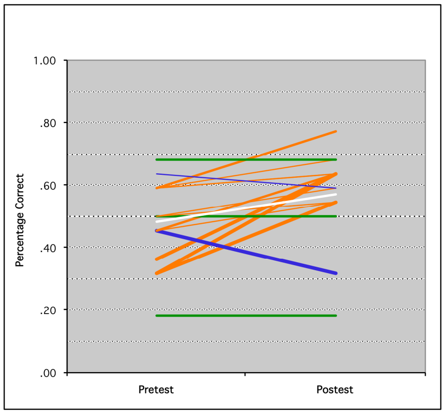

Figure 3.3. Changes in combined content and reasoning scores for individual students in Interplay investigation groups. (*Note.* From Palincsar & Magnusson, 2006)

The inclusion of the line representing mean score changes helps to illustrate that looking at means obscures much about what is occurring in terms of changes in students' understandings. In fact, relative to the wide variation in individual student data, mean changes across the three conditions appear very similar. Palincsar and Magnusson (2006) hypothesized that the prevalence of decreases in knowledge may be indicative of the classic U-shaped learning pattern revealed in the work of Karmiloff-Smith and Inhelder (1975). That is, perhaps the downward trends represent the left-hand side of a "U", and with longer instruction, would appear as positive trends and reveal different patterns in learning from instruction. Thus, the learning outcome data demonstrate a great deal of complexity. While the overall trends suggest that first-hand investigation is more effective in supporting content learning, the trends are less clear with regard to reasoning skills. Moreover, the individual student data suggest that the overall trends are actually not very telling at all.

In addition, there are many possible limitations with regard to making conclusions based on the results of written measures such as these. For example, it is possible that the assessments did not accurately capture changes in student understandings. Students may have been so challenged with regard to comprehending the assessment questions that their responses did not reflect their actual understandings. Furthermore, it has been argued that instructional capacity is determined as a result of the dynamic interaction between teachers, students, and curricular materials (Ball & Cohen, 1996; Brown & Edelson, 2003; Cohen & Ball, 1999; Remillard, 1999; 2000). The gain scores achieved from these written assessments did little to advance an understanding of this dynamism. They were only able to point to differential learning outcomes as they related to the differential instructional modes. However, a narrow focus on instructional mode alone ignores the necessary dynamism of instruction.

Thus, the findings reported by Palincsar and Magnusson (2006) suggest a need for continued research focusing on the affordances of different modes of inquiry-based science instruction when they are enacted in classroom settings. This dissertation study focused on the learning opportunities that students engaged in at a finer level than written assessments may be capable of capturing. The study attended carefully to the interactions between teachers, students, and instructional modes and thus revealed more about children's learning opportunities than the written knowledge assessments revealed. Such studies are crucial so that we are much more fully informed about what students can achieve from the actual enactment of varied instructional modes for inquiry-based science instruction.

Instructional Procedures

Three senior research team members conducted all instruction as guest teachers. For two weeks, children engaged in investigations focusing on mass-motion and force-motion relationships. During the first week of instruction, children engaged in an investigation on the topic of motion across a horizontal plane. During the second week of instruction, children engaged in an investigation on the topic of motion down an inclined plane. Each investigation in each condition took five sessions, with each session lasting between 45 and 50 minutes. Thus, children in each condition experienced a total of approximately 10 hours of instruction over two weeks with five hours of instruction occurring each week and a week inbetween each investigation.

Several factors make a study of learning in these instructional contexts, where instruction was conducted by the three university-based guest teachers, ideal for responding to the research questions. First, all three teachers in the study were highly experienced with expertise in the science content of the instruction. Because of this, a comparative study of these teachers can assume that content knowledge was held constant between the three of them, thus illuminating potential differences in pedagogical knowledge and pedagogical content knowledge (Shulman, 1987). They also jointly designed the curriculum and thus had a common understanding of its goals and activities. These factors allowed for some standardization of instruction across the settings. Thus, the differential teaching practices and learning opportunities that emerge even within this standardization are of great interest. Finally, it is also important to note that the teachers in the study were “guest teachers” who were not the students’ regular schoolteachers, and that the students had had little in the way of prior science inquiry instruction. Thus, when the researchers began instruction, they had no prior history with the students and were operating on no set assumptions about their inquiry-based learning experiences or competencies. Instead, the learning communities that developed were newly established during the two weeks that this research was conducted. This is important to note, because the study’s data capture the way that norms and conventions of the learning community evolved, thus allowing for a close study of the development of learning opportunities for scientific literacy and enculturation into scientific literacy.

Across conditions and over the course of two weeks of instruction, the instructional procedures involved three iterations of the GIsML inquiry cycle, including the *Engage, Prepare to Investigate, Investigate,* and *Prepare to Report/Report* phases.

One iteration occurred in week one while children investigated motion across a horizontal plane; and two iterations occurred in week two when children investigated motion down an inclined plane. The sequence of learning activities, per condition, is described in greater detail below. It is important to know that the GIsML instructional principles would ideally be implemented recursively, cycling through many iterations of the inquiry cycle over the course of a school year. Through these continued iterations, the teacher would likely help the students to focus on different issues. For example, at the beginning of a school year, it would be important to support students in developing an understanding of fundamental issues of scientific investigation, including the values, beliefs, norms and conventions of the scientific community. But in subsequent cycles of investigation, the teacher might determine that the students were ready to take on more sophisticated issues (Magnusson et al., 2004). However, a study such as the one described here did not have the luxury of such long-term implementation. Nevertheless, the data derived from this study capture the critical, initial cycles of investigation in the children's experience. This is valuable, because presumably these initial cycles would capture the teachers' attempts to enculturate students into scientific literacy by opportunistically providing learning opportunities about the most major and basic issues in the conduct of scientific investigation.

In the following sections, I describe the sequence of learning activities that was particular to each condition per each phase of the GIsML inquiry cycle. The phases often spanned across consecutive days. As already noted, there were two instructional groups, taught by two different teachers per condition. The teacher-researchers' intentions were to implement the same sequence of learning activities across instructional groups for each condition. However, as the results of the study will show, sometimes, due to unforeseen circumstances, teachers had to modify or even eliminate activities even though their intended purposes were the same across any two instructional groups in the same condition. The learning activities described below are the activities that were delineated in the lesson plans that were co-constructed by the teacher-researchers. In other words, the activities described below were the intended activities, though they were not necessarily enacted exactly as intended. These lesson plans for week one and week two of the first-hand investigation condition are provided in Appendices D and E respectively; and the lesson plans for week one and week two of the second-hand investigation condition are provided in Appendices F and G. One other caveat to be noted is that the lesson plans for the first-hand investigation condition identify activities focused on modeling the investigative phenomenon as part of the *Engage* phase. However, because I felt that these activities were conceptually more fitting for the *Prepare to Investigate* phase, I have identified them in that way.

The First-hand Investigation Condition

The *Engage* phase of week one of the first-hand investigation condition began with the teacher presenting a hypothetical biking scenario between himself/herself and a child in the room. The teacher told the students that the two bikers had the same kind of bike and that the race occurred across a level plane, but that they tied. Following this, the teacher engaged the students in a discussion focused on reasons why the two bikers tied or why they believe that one biker or the other should have won.

The *Prepare to Investigate* phase involved many steps and thus often spanned across two to three days. It began with the teacher engaging the students in a discussion of what it means to model an event. Following from this, the teacher handed out a worksheet (shown in lesson plans in Appendix D) and facilitated a whole group discussion where the class completed the worksheet together. The worksheet required that the students list the constructs from the race event that would need to be modeled and the corresponding objects that would model those constructs. The teacher demonstrated the materials that would be available to the students during the first-hand investigation in order to facilitate completion of these steps. From this, students completed a third column on the worksheet that required them to check off the variables that would affect the outcome of the race if they were manipulated. Finally, in the last column the students checked off the variables that they would want to manipulate in the investigation. In other words, completion of the last column would hypothetically demonstrate to the students that the variables of interest in the investigation were the mass of the riders and the pedaling force.

Once the variables had been determined, the teacher facilitated a discussion around deriving the testable questions that would guide the investigation. Students were meant to construct two questions that reflected the constructs in the investigation and two questions that reflected the constructs in the actual race event. Specifically the following were the four questions that teachers and students derived together:

How does changing the number of blocks affect the time it takes for the cart to get to the end of the board?

How does changing the number of washers affect the time it takes for the cart to get to the end of the board?

How does changing the weight of a person affect the time it takes for the bike to get to the end of the street?

How does changing a person's pedaling affect the time it takes for the bike to get to the end of the street?

Sometimes the teacher also facilitated a discussion around how these questions could be written more generally, as scientists tend to do. If this were the case, the following were the two questions that teachers and students derived together.

How does changing the mass of an object affect the time it takes to travel a certain distance?

How does changing the force on an object affect the time it takes to travel a certain distance?

At this point, time permitting, teachers put up a transparency of the investigative setup (shown in lesson plans in Appendix D) and enlisted students in a discussion around how the setup would change depending on what mass and force amounts one was investigating. Also time permitting, the teacher had students practice using a stopwatch and used overheads to demonstrate how a stopwatch should be read. Teachers sometimes had students set up the investigation simply to practice the setup of materials.

Finally, in the last activity for the *Prepare to Investigate* phase, teachers supported students in preparing a data table (shown in lesson plans in Appendix D) where they would record the data they collected during the investigation. This involved listing how many blocks would be used to represent each biker and how many washers would be used to test varying forces per biker. The data sheet allowed for students to investigate bikers of up to three different masses (represented by one, two, or three blocks) and three different pedaling forces (represented by one, two, or three washers). The data sheet also allowed for students to conduct five trials for each combination of mass and force. Finally, the teacher assigned students to groups of two or three and told each group that they were to investigate bikers of two specific masses. If students had time to investigate bikers of all three masses, they were invited to do so.

In the *Investigate* phase, students worked independently in their small groups collecting data. This phase tended to span across two days. The teacher began the second day of data collection with a brief return to the *Prepare to Investigate* phase where s/he would facilitate a discussion around what students had learned during the prior day about how to conduct an investigation in a way that achieved reliable data. After this, the students continued to collect data. While students worked independently, the teacher circulated the classroom, helping students to troubleshoot, answering questions they had, and generally discussing their findings with them.

Finally, in the *Prepare to Report* and *Report* phases, the teacher first supported students in finding a way to make sense of the large amount of data. Often using a transparency where the teacher had written some of the students' data, s/he modeled a method for identifying the median value of sets of trials. Students then tended to identify median values with all of their data. After this, the teacher facilitated a discussion around what it means to make a claim and discussed in varying detail how to use one's data as evidence for making a claim. The teacher often said that they should refer to the questions originally derived to guide the investigation and turn them into responsive statements that were supported by their evidence. The students then worked independently in their small groups to write their claims and the evidence supporting their claims on poster paper. The inquiry cycle ended with students presenting their posters. During these presentations, the teachers often supported students in asking questions of one another and in making connections between student claims.

Week two of the first-hand investigation condition included two iterations of the GIsML inquiry cycle. Many of the learning activities were similar to those that occurred during week one, so I describe those activities more generally here.

The *Engage* phase of week two began with the teacher presenting a hypothetical skateboarding race down a hill between himself/herself and another student in the class. The teacher explained that neither person pushed off but that the two riders tied. The teacher then facilitated a discussion around students' explanations of the event.

The *Prepare to Investigate* phase then followed with the teacher engaging students in completing a worksheet much like the one used in the first week. The class completed the worksheet together. Again, students were required to list the constructs from the event and the objects that would be used to model them, to identify whether changing an object/construct would affect the outcome of the race, and finally to identify which objects/constructs were the variables in the investigation. The teacher also supported the students in deriving the following testable question: "How does changing the weight of the person affect the time it takes for the person to go down the hill?" However, instead of then supporting the students in preparing for an investigation where riders of different masses were modeled and timed as they traveled down a board, the teacher first engaged the students in considering how the force of gravity was acting on people of different masses when they were at the top of the hill. The teacher then demonstrated how one could model such a phenomenon with two different strategies, one using a setup with a spring ("the spring method") and one using a setup with washers ("the washer method"). These setups are shown in the lesson plans (See Appendix E). The teacher then supported the students in deriving two testable questions about what was modeled with the spring and washer methods and about the events that they were modeling. Specifically, the following were the four questions that teachers and students co-constructed:

How does changing the number of blocks on a cart affect how much a spring that is holding it at the top of a ramp stretches?

How does changing the number of blocks on a cart affect how many washers it takes to pull it up a ramp?

How does changing the weight of a person affect the force of gravity on it at the top of a hill?

How does changing the weight of a person affect the force of gravity on it at the top of a hill?

The teacher then supported the students in organizing data tables where they would record data. S/he then assigned students to groups and assigned them to investigate the effect of a person's weight on the force of gravity at the top of a hill using either the washer method or the spring method. If time permitted, students were invited to investigate the phenomenon using both methods.

The students then continued into the *Investigate* phase. While students worked independently, the teacher circulated the classroom, helping them to troubleshoot, answering questions they had, and generally discussing their findings with them.

Because students had become familiar with the process of writing evidence-based claims, the *Prepare to Report/Report* phases followed from the *Investigate* phase without much explanation from the teacher. The teacher simply asked the students to write their claims and evidence on poster paper, and then students presented their claims. The teachers tended to separate the presentations by the method they had used (spring method or washer method) in order to facilitate connections between different groups' findings.

During these presentations, the teachers supported students in asking questions of one another and in making connections between student claims.

The second iteration of the inquiry cycle in week two actually involved students in timing the cart as it carried varied masses and traveled down an inclined plane. The *Engage* phase was very brief, its intended purpose only to remind students of the original skateboarding racing event. The *Prepare to Investigate* phase introduced the setup to the students, though they needed little explanation because the setup for the prior week's investigation had been so similar. The teacher did point out that propping the board on three dictionaries on one side would form an inclined plane. The teacher also supported the students in deriving a testable question about the phenomenon that the setup modeled: "How does changing the number of blocks affect the time it takes for the cart to get to the bottom of the ramp?" The *Investigate* phase followed, with students working independently in their already assigned small groups to collect their data. Again, while students worked independently, the teacher circulated the classroom, helping students to troubleshoot, answering questions they had, and generally discussing their findings with them. Finally, the cycle ended with the *Prepare to Report/Report* phase. The students were familiar with the process of writing evidence-based claims on the poster paper and then presenting the claims. The teacher again facilitated discussion of student claims.

The Second-hand Investigation Condition

The second-hand investigation condition followed Lesley Park's investigations in the notebook texts. Lesley's investigations and the investigations the students conducted in the first-hand investigation condition mirrored each other. However, there were obviously major contextual differences in the ways the investigations were presented and carried out. The teacher's guide to the notebook texts for week one and week two (see Appendices F and G) presents the notebook text side by side with the lesson plans for the teacher. They show when teachers could facilitate discussions around particular questions and activities in parallel with the whole group reading of the notebook text. I do not elaborate here on the learning activities, because such a description would be redundant with the descriptions in the teacher's guide lesson plans. It is worth noting, however, that of the numerous questions and activities that the teacher's guides suggest, time permitted for teachers to pick and choose only the questions and activities that they felt would be most helpful to students. Thus, the enactment of the second-hand condition varied across instructional groups based on which questions and activities the teacher decided to implement in the given time. However, what was always constant across instructional groups was the reading of the same notebook texts.

Although I do not describe in detail the learning activities and dialogue topics that teachers engaged students in for the second-hand investigation condition, I do summarize the notebook text itself and identify where the different phases of the GIsML inquiry cycle begin and end in Lesley's investigations.

The week one notebook text focused on the topic of motion across a horizontal plane and was four pages long. Before actually beginning to read the text, teachers first engaged students in a brief discussion about what scientists' notebooks are and what kind of information they may contain. The *Engage* phase began on page 1 with Lesley describing a bike race between herself and her friends Felicia and Jermaine. Though the three bikers were of varied physiques, they tied in the race. The *Prepare to Investigate* phase begins on the second paragraph of page 1 ("I decided to model…"), where Lesley describes her investigative setup of the event. She also describes how she collected data with a stopwatch and varied the mass on the cart and the amounts of force.

The *Investigate* phase only implicitly occurs, because a data table, "Table 1" showing Lesley's data is then presented on page 2, thus beginning the *Prepare to Report/Report* phase of the inquiry cycle. Lesley then describes the way that she used the Tukey procedure to determine representative values for her data. On page 3, she condenses her data showing only the representative values determined by the Tukey procedure in "Table 2." Using the evidence derived from this table, she reports the following two claims that she feels confident in making:

The greater the amount of force making an object move, the faster the object goes.

The greater the mass of an object, the slower it moves in response to the same amount of force.

Lesley continues by discussing her claims in greater detail.

On page 4, Lesley presents a reorganization of her data in "Table 3" that allows her to "more easily compare the times for the cart with different amounts of force and mass" (Notebook text, week one, page 3). Importantly, the presentation of the data on "Table 3" make it more visually salient to the reader that a tie among the three riders may easily have occurred, because the three riders obtained equal times of 1.2 seconds when different pedaling forces were applied. Lesley follows the presentation of "Table 3" with a discussion of this phenomenon and how it might have been that she, Felicia and Jermaine tied in the race.

Before actually beginning to read the notebook text for week two, teachers first engaged students in a brief review about what they had learned through Lesley's investigation in the prior week's notebook text and in discussing what they expected to find in her notebook this week. Like the first-hand investigation condition, the notebook text for week two focused on motion down an inclined plane and involved two iterations of the GIsML inquiry cycle. It was five pages long. The *Engage* phase began on page 1 with Lesley describing a skateboard race between herself and her friend, Tony. Though the two boarders were of varied physiques, were both sitting down, and did not push off, they tied in the race. Repeated trials conducted across various starting places on the hill all resulted in a tie. The *Prepare to Investigate* phase begins on the second paragraph of page 1 ("To answer my question, I chose to model…"), where Lesley describes her investigative setup of the event. She also describes how she collected data with a stopwatch and varied the mass on the cart and the amounts of force. She then describes the weights she used to model Tony and herself and the fact that she ran multiple trials.

The *Investigate* phase only implicitly occurs, because a data table, "Table 1" showing Lesley's data is then presented on page 2, thus beginning the *Prepare to Report/Report* phase of the inquiry cycle. Lesley notes that the investigation results match the outcome of the skateboard race. She expresses her surprise that mass does not affect the time it takes an object to roll down a ramp. Lesley reports her results and explains her method of investigation to her colleague, Becky. She asks Becky for help in interpreting the surprising results.

In the third paragraph on page 2 (" Becky then asked what I thought about the force…"), Becky engages Lesley in considering the role of gravity in the phenomenon, thus initiating another iteration of the GIsML inquiry cycle. The *Engage* phase begins here with Lesley and Becky considering whether the force of gravity might be different for objects of different mass.

The *Prepare to Investigate* phase begins on the fourth and final paragraph of page 2, with Becky and Lesley discussing two possible procedures for measuring the force of gravity for different amounts of mass. This discussion continues on page 3, where Lesley describes the spring method and then the washer method. Lesley also describes what ideas gave rise to these methods. It is relevant to note here that the order of the topics of investigation for the two iterations of the GIsML inquiry cycle in week two are opposite in the first-hand investigation and second-hand investigation conditions. Whereas students in the first-hand investigation condition first investigated the effect of gravity on objects of different mass and then studied the time it takes objects of different mass to roll down a hill, students in the second-hand investigation condition investigated the role of gravity after studying the time it takes objects of different mass to roll down a hill.

The *Prepare to Report/Report* phase begins on page 4 and continues through page 5. The phase begins with Lesley's presentation of "Table 2" and "Table 3" which present the data collected from the spring method and washer method respectively. Using the evidence derived from these tables, she reports the following two claims:

The greater the mass, the greater the force of gravity on it at the top of a ramp.

The force of gravity increases by the same amount that the mass increases: twice the mass has twice the amount of force on it; three times the mass has three times the amount of force on it.

Lesley continues by discussing her claims in greater detail. She realizes that her first investigation examining the time it takes objects of different mass to roll down a hill was not a fair test, because she was simultaneously varying two variables, the mass and the force on the cart. The notebook ends with Lesley relating her thoughts about the mass-force relationship back to the original skateboarding phenomenon. She exclaims, "So, mass did influence what happened in the race because Tony’s greater mass also meant the force of gravity was greater on him. Tony had more mass to move, but he also had a larger force to make him move” (Notebook text, week two, page 5).

The Interplay Condition

For week one, the interplay condition featured first-hand investigation as the mode of investigation. Thus, the instructional groups in the interplay condition followed the exact same sequence of learning activities as the first-hand investigation condition. For week two, the interplay condition featured second-hand investigation as the mode of investigation. Thus, the interplay instructional groups followed the exact same sequence of learning activities as the second-hand investigation condition. One very small difference was that at the beginning of the second week of instruction, the teachers reminded students that they had engaged in first-hand investigations during the prior week and that this week they would be engaging in a second-hand investigation, explaining briefly what a second-hand investigation was. The teacher also engaged students in discussing what a scientist’s notebook is and what they would likely find in one.

Data Sources

The main data source is video footage captured on mini DVs that was collected during all instruction. Each mini DV captured one lesson that was approximately 45-50 minutes long. There were 60 mini DVs in total. The DVs were then transferred to DVD. For the most part, video footage followed the speaker during whole group instruction and followed the teacher when children worked in pairs of groups of three. There were approximately two hours of missing data due to technical problems with the video footage. The two tapes that recorded instruction in Ms. Allen's interplay group and Mr. Cannon's interplay group on October 21. 2003 were both damaged. There were also a few isolated instances across the data corpus where the audio of the video recording was accidentally not collected. These cases were spread out across instructional modes and teachers and lasted only a few minutes, such that there is not a high concentration of missing audio for any one instructional group.

I also reviewed in great detail the curricular materials that were used for the unit, including the lesson plans for the first-hand investigations (see Appendices D and E), the lesson plans for the second-hand investigations (see Appendices F and G), the notebook texts (shown in lesson plans for second-hand investigations in Appendices F and G), descriptions of teaching practices that were consistent with each phase of the GIsML inquiry cycle that had been developed by other GIsML researchers (see Appendix H), and my own observational notes taken during a pilot study aimed at broadly characterizing the instructional settings featured in the video corpus (see sample in Appendix I).

Data Analyses

The data analyses consisted of two phases, a macro-level video-analysis and a micro-level case study analysis. This two-phase procedure allowed for a broad-stroke exploratory analysis of a wide set of data to direct the more narrow and purposeful subsequent analysis. Each of these phases is described in greater detail below and is presented in a condensed format in Table 3.3.

Table 3.3
Data Analysis Design

Research question	Data source	Broad Analytical Purpose	Specific Analytical Steps
What are the differential opportunities students have to engage with scientific practices and to acquire accurate conceptual understandings in a first-hand, second-hand or first-hand followed by second-hand investigation?	lesson plans for the first- and second- hand investigations descriptions of teaching practices that were consistent with each phase of the GIsML inquiry cycle observational notes taken during a pilot study	Preparation for macro-analytical video viewing	1. Review curricular materials. 2. Develop GIsML motion unit of study guiding framework. 3. Develop Observation Summary Sheet.
	DVDs of all instruction	Conduct of Macro-analytical video-viewing	4. Chronologically view each DVD of instruction. Record observational notes and time stamps during viewing. 5. Complete observation summary sheet per DVD.
	Observation summary sheets	Summarizing the Macro-analytical Video Viewing and Preparing for the Micro-Analytical Case Studies	6. Consolidate observation summary sheets per phase of instruction per instructional group. 7. Record frequency “practices score” and “claims score” per week per phase of instruction per instructional group. 8. Calculate time that each instructional group spent per week per phase of instruction. 9. Identify rich and lean cases per week per phase of instruction.
What mediates the learning opportunities for engaging with scientific practices and acquiring accurate conceptual understandings across and within conditions?	Observational notes taken during macro-analytical video viewing DVDs of instructional episodes occurring on days targeted for case studies	Conducting the Micro-analytical Case Studies	10. Review observational notes and DVDs of instruction to identify representative segments of instruction per each rich and lean case. 11. Transcribe representative segments. 12. Attend to the opportunities for engaging with scientific practices and conceptual claims in rich and lean cases. Engage in microanalyses utilizing lenses that focus on participant structures, connections to prior experiences, and argumentation. 13. Formulate assertions per rich and lean case that are revealed by my analyses. 14. Engage in comparative analysis where I juxtapose assertions per set of contrastive case studies in a summary table, when the assertions appear related. 15. Engage in cross-case analysis and elaborate upon assertions per analytical lens.

Preparing for the Macro-analytical Video Viewing

In order to guide the macro-analytical video viewing, I first developed a framework for the GIsML motion unit of study. The framework included the guiding questions, purposes for engaging in scientific practices, the actual scientific practices that students were likely to engage in, and conceptual goals for each of the *Engage, Prepare to Investigate,* and *Prepare to report/Report* phases of instruction in the GIsML motion program of study. I developed the framework by carefully reviewing the following materials: the lesson plans for the first-hand investigations (see Appendices D and E), the lesson plans for the second-hand investigations (see Appendices F and G), the notebook texts (shown in lesson plans for second-hand investigations in Appendices F and G), descriptions of teaching practices that were consistent with each phase of the GIsML inquiry cycle that had been developed by other GIsML researchers (see Appendix H), and my own observational notes taken during a pilot study aimed at broadly characterizing the instructional settings featured in the video corpus (see sample in Appendix I).

For the purposes of the analysis, the *Prepare to Report* and *Report* phases were condensed and addressed as one phase, because the distinction between the two phases was often subtle or even nonexistent. I could not attend to the *Investigate* phase primarily because the research had called for following the teacher; thus most of the video footage had not audibly captured the small group discussion that occurred when students worked in pairs or groups of three during the *Investigate* phase in the first-hand investigation. Also, in the second-hand investigation context, the *Investigate* phase only implicitly occurred. In the notebook, Lesley simply reported on how she prepared for the investigation and then reported the results. Thus, in this context, the students went directly from *Prepare to Investigate* to *Prepare to Report/Report.* In addition, I made the assumption that the intellectual work that had occurred during the *Investigate* phase would mostly likely also be captured in the whole group discussion during the other phases. Of course, it is possible that this limitation of the data set prevented me from attending to all of the intellectual work that children engaged in while conducting first-hand investigations during the *Investigate* phase. In other words, to the extent that the intellectual work that children engaged in during the *Investigate* phase was not also captured in whole group discussion that occurred during other phases of instruction, my analyses did not fully capture children's thinking.

I also designed an observation summary sheet (see Appendix J) that I would use to track the aspects of scientific literacy, capturing both the scientific practices and conceptual claims, which students engaged with across all instruction. A review of the curricular materials influenced the design of the observation summary sheet. For example, with regard to the scientific practices that I decided to track, the lesson plans for both the first- and second-hand investigation modes guided teachers in conducting activities where they were engaging children in considering how to model a scientific phenomenon. In the first-hand investigation context, the lesson plans showed that children would be supported in discussing how they could use materials to model the biking race phenomenon and then set up the materials themselves before data collection. In the second-hand investigation context, the lesson plans showed that children would read about and discuss the way that Lesley modeled the biking race phenomenon she had experienced in her race against Jermaine and Felicia. An additional suggested activity for use with the notebook text was that students could label the parts of the model in an illustration. My review of the entire set of curricular materials revealed that instruction across the instructional modes would likely engage children in the following nine scientific practices: 1. Deriving a testable question; 2. Systematically manipulating variables; 3. Running multiple trials; 4. Modeling a phenomenon; 5. Measuring variables; 6. Organizing the recording of data; 7. Interpreting a data table; 8. Identifying patterns in a data table. 9; Comparing knowledge claims. Thus, I included these nine practices on the observation summary sheet to track children's engagement with scientific practices. I also reviewed the notes that I had taken during a pilot study to confirm that these nine practices tended to accurately characterize the practices that students actually engaged with during instruction. Table 3.4 provides examples of learning activities that I observed in my pilot study that exemplified student engagement with each of these practices.

Table 3.4
Exemplars of Learning Activities that Characterized Engagement with the Focal Scientific Practices

Scientific Practice	Example of Learning Activity That Engaged Students in Considering the Scientific Practice
Deriving a Testable Question	Students orally articulate the questions that they will investigate with the investigative setup.
Systematically manipulating variables	Students identify data cells in a table that depict an increasing mass while force is held constant.
Running multiple trials	Students discuss the benefit of running multiple trials during data collection.
Modeling a phenomenon	Students label an illustration of the investigative setup.
Measuring variables	Students practice using stopwatches to measure time.
Organizing the recording of data	Students label a data table where they will record the data they collect during their investigations.
Interpreting a data table	Students locate the data cell on a table that shows the time it takes for a cart that models a mass of two blocks and a pedaling force of three washers to travel across the board.
Identifying patterns in a data table	Students recognize that the data on a table show that as force increases but mass is constant, the cart takes less time to travel across the board.
Comparing knowledge claims	Students consider whether their mass-motion and force-motion claims are the same as claims posed by Lesley in the notebook text.

In order to support my tracking of the substantive aspects of scientific literacy that students engaged with, I developed a classification scheme for the actual conceptual claims that students made. I reviewed my observational notes taken during my pilot study and determined that students tended to make claims that fit under one of the following three general arguments: (1) Mass determines who will win; (2) Force determines who will win; or (3) The mass-force relationship determines who will win. Sometimes there were miscellaneous, tangential arguments that I tracked under a category labeled as “other.” Thus, I included these four categories on the observation summary sheet to track children's actual knowledge claims. I reviewed the notes that I had taken during a pilot study to confirm that these four categories tended to accurately characterize student claims. Table 3.5 provides examples that I observed in my pilot study that exemplified each category of student-posed conceptual claims.

Table 3.5
Exemplars of Student-posed Conceptual Claims that Characterized Each Category of the Claim Classification System

Conceptual Claim Category	Example of Student-posed Conceptual Claim
Mass determines who will win.	Ted (First-hand, Mr. Cannon): If the cart has three blocks on it instead of one block, it will be heavier so then it won't go as fast.
Force determines who will win.	Kiely and Mia (First-hand, Ms. Baker): The more washers there are on the string, the faster the cart goes.
The mass-force relationship determines who will win.	Leah (Interplay, Ms. Allen): For heavier people, gravity just wants you to go down. It pulls more on heavier people.
Other	Lena (Interplay, Mr. Cannon): If the two bikes are exactly the same, they should go exactly the same speed, no matter how much force you have or how heavy you are.

Conducting the Macro-analytical Video Viewing

I then conducted the macro-analysis viewing of the data corpus, viewing each tape in the data corpus chronologically per each instructional group. Watching the tapes in such a sequence enabled me to develop an understanding of the "story" and "characters" involved in each instructional group. As I watched each tape, I recorded broad but continuous observational notes, insuring specifically that I had captured when teachers and students engaged in the targeted scientific practices (which I had identified when writing the framework for the GIsML motion unit of study) and in making conceptual claims. I also recorded time stamps that identified where each phase of the GIsML inquiry cycle began and ended so that I could return to these notes to guide my subsequent microanalysis. I also made note of any particularly noteworthy events, such as instances where there were behavior problems, where students or teachers appeared to struggle, or where students who rarely participated became involved, etc. Generally though, my goal was to capture what aspects of scientific literacy the students engaged in.

After I had viewed each video capturing each 45-50 minutes lesson, I referred to my observational notes to complete the observation summary sheet for that lesson by checking off the scientific practices that students had either engaged in themselves or had considered and discussed. For example, although students in the second-hand investigation context may not have measured variables themselves, they often considered and discussed the way that Lesley did so. I then referred to my observational notes to also record the conceptual claims that students had made. I found that at any time when the students worked in partners or small groups of three, the audio was often of poorer quality, so analysis during these phases would not offer a clear understanding of the instructional setting. So although I did take observational notes during those segments, I only took into account whole-group discussion in what I recorded on the observation summary sheet.

Summarizing the Macro-analytical Video Viewing and Preparing for the Micro-analytical Case Studies

I used the observation summary sheet both to respond to the first research question and to identify the contrastive cases, which were the grist for the second research question. The observation summary sheets permitted me to explore the degree of congruence between the “ideal” and the “realized” instruction. Generally speaking, ideal cases would provide many opportunities for engaging in scientific literacy, reflected in students’ engagement in a high number of scientific practices and also a high number of conceptual claims that were related to mass-motion and force-motion arguments.

But in order to be able to assess the degree of congruence between “ideal” and “realized” instruction, there were several steps I first took to summarize the information I had captured on the observation summary sheets. I began by consolidating the observation summary sheets per instructional group, per inquiry phase, per week. Thus, for any one instructional group, there were three consolidated groupings of observational sheets for week one, all relating to the study of motion across a horizontal plane: the *Engage* sheets, the *Prepare to Investigate* sheets, and the *Prepare to Report/Report* sheets. Then there were three consolidated groupings of observational sheets for week two, all relating to the study of motion down an inclined plane: the *Engage* sheets, the *Prepare to Investigate* sheets, and the *Prepare to Report/Report* sheets. For each grouping, I used my time stamp recordings to calculate the total amount of time that each instructional group spent in each phase of the inquiry cycle per week. I then tallied the number of scientific practices that students engaged in and the number of mass-motion and force-motion claims that students made, thus producing a “practices score” and a “claims score” per instructional group, per inquiry phase, per week. In other words, this process captured what practices and claims the students in each instructional group were engaged with for each phase of instruction per week.

This process of calculating practices scores, claims scores and time stamps allowed me to respond to my first research question, which broadly asked, “*What* *opportunities do students have to engage in scientific practices and to acquire accurate conceptual understandings in a first-hand-, second-hand- or first-hand- followed by second-hand- investigation?"* I compared practices scores and claims scores to determine if there were differential opportunities to engage with greater or fewer scientific practices and conceptual claims across conditions. In addition to this, I considered the time stamp data to determine if instructional time was utilized differently across conditions. This information was important, because it was a potential explanatory factor for differences in the practices scores and claims scores across conditions.

Two caveats are important to note here. First, it is relevant to note again that in week two students engaged in two iterations of the inquiry cycle, where the overall topic of the investigations was motion down an inclined plane. I decided to collapse the practices score and the claims scores for those two inquiry cycle iterations. This allowed for the most judicious approach to evaluating the relative richness of opportunities for learning scientific literacy across instructional groups, particularly because the sequence of the topics of the two inquiry cycles was reversed across first-hand and second-hand investigations. By collapsing the scores for the two cycles, I could consider the practices score and claims scores for the entire second week globally.

Second, it is also important to note that I did not attend to the accuracy of the claims in determining the claims scores for the *Engage* and *Prepare to Investigate* phases. At these points in the investigations, inaccuracy of the claims did not subtract from the richness of opportunities for learning, as it was expected that students would come to the learning experience with some inaccurate conceptions. However, for the claims scores for the *Prepare to Report/Report* phase, I did attend to the accuracy of claims. At this point it was expected that students would be arriving at more correct conceptual conceptions, and so only more correct conceptual claims that took into account how the mass-force relationship affected an object's speed were counted toward the claims score.

My next steps required that I make judgments with regard to the relative richness of the opportunities for learning across instructional groups. For example, I wanted to determine if there were groups that provided consistently richer or leaner instructional moments. The results of this analysis would also inform which cases I chose for the micro-analytical case studies. I wanted to identify the richest and leanest case per week per phase of instruction, resulting in a total of six sets of contrastive cases. Thus, I took several steps in determining relative richness and leanness of the opportunities for students to engage in scientific literacy for each instructional group per phase of instruction per week. Table 3.4 presents these steps in summarized form, showing each criterion I considered in order of importance. If a superordinate criterion still resulted in some ambiguity about which cases were richest and leanest, I then considered the next subordinate criterion. I elaborate more fully on each of these criteria below.

Table 3.6
Order of Criteria Considered in Identifying Richest and Leanest Cases

Ordinate Level	Criteria Used to Identify Rich Cases	Criteria Used to Identify Lean Cases
1	Highest practices and claims scores	Lowest practices and claims scores
2	Strong balance between practices and claims scores	Poor balance between practices and claims scores
3	Strong balance between practices and claims scores achieved within short amount of time	Strong balance between practices and claims scores achieved within long amount of time
4	High student participation with scientific practices and conceptual claims	Low student participation with scientific practices and conceptual claims

At a most basic level, richest cases would reflect student engagement in the most scientific practices and the most mass-motion and force-motion conceptual claims, while leanest cases would reflect student engagement with the least scientific practices and the least conceptual claims. However, the next criterion I considered was whether a case demonstrated a strong balance between the scientific practices and conceptual arguments that students engaged with. For example, if a case involved students in engagement with ten practices but only one conceptual claim, I judged it as being less rich than a case that involved students in engagement with four practices and seven arguments. This determination was based on the study's foundation in considering scientific literacy to be an integration of syntactic and substantive knowledge (Schwab, 1962). One caveat to note, however, is that the *Engage* phase was sometimes an exception to this rule. In this phase, students sometimes did not engage in the identified scientific practices; instead the focus of discussion tended to be on conceptual arguments alone. When this was the case across instructional groups for a particular phase and week, richness was not based on a balance between practices and claims but rather on the number of relevant conceptual claims alone.

I also determined that if consideration of the above factors still resulted in some uncertainty with regard to which cases could be deemed the richest and leanest per phase per week, I would consider the amount of time that the phase spanned. For example, an instructional group that reached a strong balance between practices and claims within 45 minutes of instruction would be deemed richer than a case that reached a similar balance between practices and claims only after 120 minutes of instruction. When all of the above factors still resulted in some uncertainty, I considered the student participation in engagement with scientific practices and conceptual claims. Cases where more students were engaged as compared to fewer students were deemed richer.

Thus, this process of evaluating cases led to the identification of six sets of contrastive cases (or six rich cases and six lean cases), with one rich and one lean case identified per week per phase of instruction. This process was also responsive to the first research question in that it broadly demonstrated whether particular instructional groups provided consistently richer or leaner opportunities for engaging in scientific literacy. It also provided the grist for the second research question, which I responded to more fully via the micro-analytical case studies.

Conducting the Micro-analytical Case Studies

As I have noted, during week two, the sequence of the topics of the two inquiry cycle iterations was reversed across instruction featuring first-hand and second-hand investigations. Students who engaged in first-hand investigations first investigated the mass-gravity relationship and then investigated the time it took for carts carrying varied masses to travel down an inclined plane. Students who engaged in second-hand investigations first investigated the time it took for carts carrying varied masses to travel down an inclined plane and then investigated the mass-gravity relationship. This additional variable confounded close comparisons of instructional modes in week two. A fine-grained analysis of learning opportunities in week one could isolate factors related to instructional mode, whereas such an analysis of week two could not. Due to this factor, I decided to fully develop only the three sets of contrastive case studies from week one in the micro-analysis. Thus, I focused my fine-grained microanalysis on case studies of the three rich cases from week one juxtaposed with the three related lean cases.

With the three sets of contrastive cases from week one identified, I was able to conduct the micro-analytical case studies, which responded to the second research question, "W*hat mediates the learning opportunities for engaging with scientific practices and acquiring accurate conceptual understandings across and within conditions?"* This process involved a series of steps. I first identified segments from each contrastive case that were representative of the types of activities represented in the GIsML heuristic diagram (see Appendix A) that guided the design of the GIsML motion unit of study. The *Engage* phase, however, was quite short across instructional groups, so I simply transcribed the whole phase of instruction. For the *Prepare to Investigate* phase, I aimed to transcribe segments where students were engaged in deriving the testable question, preparing to use needed materials for the investigation, and deriving a method of investigation. For the *Prepare to Report/Report* phase, I aimed to transcribe segments where children were engaged in deriving evidence-based claims and in publicly sharing and explaining their findings. In order to identify these segments, I reviewed the macro-analytical video observational notes to narrow down my selection to potential segments. Then, if necessary, I watched the potential segments again to decide upon which were most representative of activities included in the GIsML heuristic for that phase of the investigation for that particular instructional group. Once I had identified the representative segments, I transcribed them.

I followed transcription of these segments with a microanalysis aimed an uncovering what characteristics of the instructional setting led to the varied opportunities for learning in those particular segments. In other words, my analysis aimed to uncover the differences in the instructional settings across the cases that led to the relative richness of opportunities for learning captured in the macro-analysis. I attended to this analysis with three different analytical lenses, each already featured in the literature review as integral components of the study's logic of inquiry: a participant structure lens, a connections to prior experiences lens, and an argumentation lens. As I have noted already, these microanalyses were designed to respond to the second research question that asked, "*What mediates the learning opportunities for engaging in scientific practices and acquiring accurate conceptual understandings across and within conditions?"* Thus, when I analyzed the representative transcript segments for each set of contrastive case studies, I was most interested in understanding the way that participant structures, students' connections to prior experiences, and student-posed conceptual arguments were mediated to move students toward engaging in scientific practices and acquiring accurate conceptual understandings. I was particularly attentive to the way that teacher discourse moves facilitated this type of engagement.

It is important to note that this phase of analysis was conducted from an interpretive stance. My findings were based on my interpretive responses to a set of guiding questions per analytical lens. These guiding questions are presented in Table 3.5.

Table 3.7
Guiding Questions for Each Analytical Lens

Analytical Lens	Guiding Questions for Micro-analytical Case Studies
Participant Structure	If students were perceived as having ideas that were either worthwhile or not worthwhile, what features of the instructional setting (curricular attributes, teacher moves/characteristics, or student moves/characteristics) potentially positioned the student in this way?
Connections to Prior Experiences	If a student makes a connection to a prior experience, • what preceding or following interactions, (with a curricular attribute, teacher, or student, if any) supported the student in making this connection? • what subsequent interactions (with a curricular attribute, teacher or student, if any) built upon the student's connection to the prior experience?
Argumentation	If a student generates a conceptual argument/claim, • what preceding or following interactions (with a curricular attribute, teacher, or student, if any) supported the student in making the conceptual claim? • what subsequent interactions (with a curricular attribute, teacher or student, if any) built upon the student's conceptual claim?

In order to confirm the dependability of my analytical method as well as the interpretations I made based of the data, I enlisted the participation of an independent rater. I requested the rater to evaluate a total of one hour's worth of video excerpts across the three sets of contrastive cases. I also provided him with the related transcript excerpts for those segments and asked that he respond to the guiding analytical questions in relation to those excerpts. I found that, indeed, the independent rater's interpretations were consonant with mine, thus confirming that I was not making high-inference interpretations. In Appendix K, I provide a table that lists two transcript samples and my interpretations of them per analytical lens. Also included in the table are annotations I recorded of the independent rater's interpretive comments.

These analyses led me to make several assertions that were warranted by my observations with regard to the features of the instructional settings that mediated the learning opportunities provided. For each set of contrastive cases, I engaged in a comparative analysis, juxtaposing my assertions across the two cases to see if there were relationships across them. In other words, my goal was to relate differences in the learning opportunities provided to differences in the instructional contexts. I did not assume that these instructional differences could only be set in motion by the teacher. I assumed that each instructional setting was formed by an interaction of three factors: teacher actions, student actions, and curricular attributes (Ball & Cohen, 1996; Brown & Edelson, 2003; Cohen & Ball, 1999; Remillard, 1999; 2000). The interaction of these three factors clearly led to very different opportunities for engaging in scientific practices and for formulating conceptual claims. Thus, I also made notations capturing the source(s) (teacher, student, and or curricular mode) that enabled or disabled opportunities for engaging in scientific practices and acquiring conceptual understanding.

If there were relationships between the two contrastive cases, such as a striking similarity or difference, I juxtaposed them in a table that summarized my assertions per set of contrastive cases. If there did not seem to be a relationship between assertions across the two contrastive cases, I simply listed them singly without a pairing in the contrastive case. These summative tables of assertions per set of contrastive cases are provided in Appendix L.

Finally, based on a cross-case analysis of my findings across the three sets of contrastive cases, I distilled my findings per each analytical lens, focusing on participant structures, connections to prior experiences, or on argumentation. I elaborate fully on these findings in Chapter 5, organizing my findings by analytical lens.

Ethics

I also note here that I have taken steps to engage in this study in an ethical manner. First, as I have already noted, in order to protect the anonymity of study participants, all names of participants, including both teachers and students, are pseudonyms. Secondly, in the reporting of my analyses, I acknowledge that it was not possible for me to know or understand the entire set of circumstances that teachers faced with regard to their instructional enactment. While I have tried to derive logical conclusions based on the evidence provided by the study's data, I also note that there may certainly have been alternative explanations that my analyses did not elicit. For example, I report conclusions that I derived about teachers' roles in the provision of relatively lean opportunities for engaging with scientific practices and conceptual claims. However, it is likely that there were many situational factors, such as space or resource issues, as well as teacher intentions, that I was unaware of because they were not captured in the study's data. These unknown factors could potentially have been very influential upon teacher actions. In other words, I acknowledge that the conclusions I report may be based upon an incomplete understanding of the factors that teachers faced when making instructional decisions.

CHAPTER 4: MACRO-ANALYTICAL FINDINGS

Overview

This chapter presents the results of the macro-analytical video viewing. These results respond to the first research question, which asked, "*What are the differential opportunities students have to engage with scientific practices and to acquire accurate conceptual understandings in a first-hand, second-hand or first-hand followed by second-hand investigation?"* I first provide the guiding framework I developed for the GIsML motion unit of study. I then report the frequency counts of scientific practices and conceptual claims that students in each instructional group engaged with across each phase of the GIsML inquiry cycle for each week of instruction. I then report which cases I identified as the richest and leanest case for providing students with opportunities for engaging with scientific literacy and conceptual claims per week per instructional phase. Lastly, I provide the time measures that each instructional group spent in each phase of instruction. All of these results collectively respond to the first research question.

Before reporting the results of these analyses, a few caveats are in order. First, it is important to recall that the students in this study had no prior experience with scientific inquiry. Second, the implementation of this study occurred over the course of only two weeks; and while at first glance, this may appear to be a very short duration, science instruction of this depth was rarely implemented at this specific school site nor in general across American classrooms (Weiss et al., 2001; Weiss et al., 2003; Weiss & Pasley, 2004;). Thus, the results that are reported here are specific to this instructional context and may not be generalizable to all other contexts.

In addition, it is important to recognize that the GIsML motion unit of study that was enacted in this study addressed particularly complex and abstract conceptual terrain. The issues of force, motion and gravity are abstract topics, unlike other more concrete or tangible areas of study, such as plant taxonomy or animal life cycles. Gunstone and Watts (1985) asserted that children's beliefs with regard to the learning of mechanics are particularly firmly held and difficult to change. Several studies have found that even successful physics students frequently retain common pre-instruction conceptions of the world in the face of counterevidence (Champagne, Klopfer, & Anderson, 1980; Clement, 1982; Gunstone & White, 1981). Thus the findings reported here may be more pertinent to instruction addressing similarly complex and abstract conceptual terrain. It is indeed possible that the findings I report would not transfer to other contexts that involve instruction in more concrete and tangible conceptual terrain.

The Guiding Framework for the GIsML Motion Unit of Study

I carefully reviewed curricular materials for the GIsML motion unit of study to inform my development of a guiding framework. The guiding questions, purposes for engaging in scientific practices, and conceptual goals of instruction were constant across conditions. Table 4.1 presents this information for the GIsML motion program of study.

Table 4.1
Framework for the GIsML Motion Program of Study

	Engage	Prepare to Investigate	Report/Prepare to Report
Guiding Question	What is the relationship between mass and motion and between force and motion when studying the motion of an object across a horizontal plane and down an inclined plane?	How does one set up a fair investigative test of mass-motion and force-motion relationships when studying the motion of an object across a horizontal plane and down an inclined plane?	How does one interpret data in order to generate claims about mass-motion and force-motion relationships when studying the motion of an object across a horizontal plane and down an inclined plane?
Purposes for Engaging with Scientific practices (Syntactic Knowledge)	Students are engaged with scientific practices for the purpose of considering multiple arguments that explain why people of different mass tie in a bike race on a level plane and in a skateboard race down a hill.	Students are engaged with scientific practices for the purpose of understanding their roles in setting up a fair test of motion across a horizontal plane and down an inclined plane.	Students are engaged with scientific practices for the purpose of generating evidence-based claims about mass-motion and force-motion relationships when studying an object's motion across a horizontal plane and down an inclined plane.
Scientific practices (Syntactic Knowledge) that students may engage with	deriving a testable question systematically manipulating variables running multiple trials modeling a phenomenon measuring variables organizing the recording of data interpreting a data table identifying patterns in a data table comparing knowledge claims	deriving a testable question systematically manipulating variables running multiple trials modeling a phenomenon measuring variables organizing the recording of data interpreting a data table identifying patterns in a data table comparing knowledge claims	deriving a testable question systematically manipulating variables running multiple trials modeling a phenomenon measuring variables organizing the recording of data interpreting a data table identifying patterns in a data table comparing knowledge claims
Conceptual Goals of Instruction (Substantive Knowledge)	Students are considering the relative speed of objects of differing mass as they move across a horizontal plane and down an inclined plane. Students are considering the effects of force and mass on the speed of objects as they move across a horizontal plane and down an inclined plane.	Students are considering the relative speed of objects of differing mass as they move across a horizontal plane and down an inclined plane. Students are considering the effects of force and mass on the speed of objects as they move across a horizontal plane and down an inclined plane.	Students conclude that objects of greater mass travel more slowly across a horizontal plane when force is held constant. But applying greater force can compensate for the mass disadvantage. Students conclude that although objects of greater mass would theoretically travel more slowly down an inclined plane when no force is applied, the force of gravity is greater on objects of greater mass. Thus, objects of different mass travel down an inclined plane at the same speed.

As shown, this analysis revealed that the instructional foci of the different phases of instruction were unique. As I have also noted in Chapter 3, students were expected to be arriving at accurate and specific conceptual understandings by the final phase of the inquiry cycle, the *Prepare to Report/Report* phase. In previous phases, it was expected that they would still be considering multiple arguments to explain the motion of an object across a horizontal plane and down an inclined plane. With this critical difference in mind, it follows that students would also be guided by different questions and be engaged in scientific practices for very different purposes across phases. In general, the guiding questions and purposes for engaging in scientific practices moved children initially from a broad focus of considering multiple arguments to a specific focus on collecting reliable data and then to a focus on interpreting data to support conceptual claims.

I also note here that the curricular materials, particularly the pilot study observational notes, revealed that there were no clear demarcations among scientific practices that students actually engaged in across phases. While it did seem most likely, for example, that students would derive testable questions in the *Engage* or *Prepare to Investigate* phases, it sometimes happened that students derived testable questions during the *Prepare to Report/Report* phases. Thus, as shown in Table 4.1, I concluded that students might engage in any of the nine listed scientific practices during any phase of instruction.

General Trends in Practices Scores and Claims Scores

The macro-analytical video viewing yielded frequency counts of scientific practices (practices scores) and conceptual claims (claims scores) that students in each instructional group engaged with per phase of the GIsML inquiry cycle in each week of instruction. Those findings are summarized in Table 4.2.

Table 4.2
Practices Scores and Claims Scores for Each Instructional Group per Phase of GIsML Inquiry Cycle

		Week One: Motion Across a Horizontal Plane		Week Two: Motion Down an Inclined Plane	
		Scientific practices	Conceptual Claims	Scientific practices	Conceptual Claims
Engage	First - Baker	0	5	0	5
	First - Cannon	0	4	0	7
	Second – Baker	0	5	1	3
	Second - Allen	1	5	4	11
	Interplay - Allen[*]	0	8	1	11
	Interplay - Cannon[*]	0	8	2	12
Prepare to Investigate	First - Baker	6	2	4	3
	First - Cannon	7	1	4	0
	Second - Baker	3	3	6	0
	Second - Allen	3	10	8	9
	Interplay - Allen[MD*]	5	0	7	9
	Interplay - Cannon[MD*]	6	0	4	11
Prepare to Report/Report	First - Baker	5	0	6	10
	First - Cannon	3	1	7	7
	Second - Baker	7	2	5	3
	Second - Allen	9	5	7	14
	Interplay - Allen[*]	6	2	4	1
	Interplay - Cannon[*]	4	2	3	6

MD = These cases had some missing data in week one.
* = During week one, these instructional groups experienced first-hand investigation; and during week two, they experienced second-hand investigation.

A general analysis of the results reported in Table 4.2 focused on relationships across weeks of instruction, phases of instruction, and frequency counts of scientific practices and conceptual claims. There are two clear claims that I can make with regard to the findings shown in Table 4.2. As expected, across instructional groups, students engaged in fewer scientific practices in the *Engage* phase as compared to other phases. For example, during the *Engage phase* in week one, five of the six instructional groups engaged in no literate practices at all; and in the *Engage* phase of week two, only one group engaged in more than two scientific practices. This phase of instruction was particularly conducive to eliciting conceptual claims as its purpose was to guide students in considering multiple conceptual arguments. This finding is consistent with calls for instruction to elicit students' prior conceptions at the start of instruction (Donovan & Bransford, 2005; Lampert, 1990; Smith, Maclin, Grosslight, & Davis, 1997). The results I report parallel these calls, because the instructional focus was largely on eliciting students' initial conceptions or conceptual claims as compared to engaging students in scientific practices.

Secondly, across instructional groups, apart from the *Engage* phase, in week one students tended to engage in more literate practices as compared to the conceptual claims that they engaged with during the same phase of instruction. But in week two, there was a greater balance between students engaging with scientific practices and conceptual claims. For example, Ms. Baker's first-hand investigation group engaged with far more practices than claims in both the *Prepare to Investigate* phase (6 practices and 2 claims) and *Prepare to Report/Report* phase (5 practices and 0 claims) of week one. But in week two, her students engaged with practices and claims in a more balanced way in both the *Prepare to Investigate* phase (4 practices and 3 claims) and *Prepare to Report/Report* phase (6 practices and 10 claims). I observed this pattern of improving balance across the two weeks in most of the instructional groups. This suggested that, by week two, teachers may have felt it was less necessary to explicitly guide students to engage in scientific practices in service of conceptual understandings. The students may have become more proficient at thinking conceptually, based on their experience with inquiry learning in week one.

Selection of Contrastive Case Studies

The general findings reported above, however, did not respond to my research question that aimed to uncover differences across instructional modes. Toward this purpose, I engaged in a more detailed analysis focused on differences amongst instructional groups. This analysis influenced my choice of contrastive cases for the microanalysis. As discussed in the previous chapter, per phase of instruction, the instructional groups that engaged with the most and least practices and claims were chosen as the cases to demonstrate the richest and leanest opportunities for learning scientific literacy respectively. There were some complex comparisons, however, that involved making a selection between two cases based on the more detailed criteria described in chapter 3 and summarized in Table 3.4. When this was the case, I describe the decisions that led to my selections in more detail in the following chapter. In Table 4.3, I report which contrastive cases I selected.

Table 4.3
Contrastive Case Selections per Week per Phase of GIsML Inquiry Cycle

Week	Phase of Instruction	Richest Opportunities for Engaging in Scientific Literacy	Leanest Opportunities for Engaging in Scientific Literacy
Week One	Engage	Interplay (First) - Mr. Cannon*	First - Mr. Cannon
	Prepare to Investigate	Second - Ms. Allen	First - Mr. Cannon
	Prepare to Report/Report	Second - Ms. Allen	First - Ms. Baker
Week Two	Engage	Second - Ms. Allen	First - Ms. Baker
	Prepare to Investigate	Second - Ms. Allen	First - Mr. Cannon
	Prepare to Report/Report	Second - Ms. Allen	Interplay (Second) - Ms. Allen*

* = During week one, these instructional groups experienced first-hand investigation; and during week two, they experienced second-hand investigation.

Differences in Practices Scores and Claims Scores Across Instructional Groups

The findings reported in Tables 4.2 and 4.3 were not only integral in influencing the subsequent microanalysis, but they were also responsive to the first research question, which asked "*What are the differential opportunities students have to engage in scientific practices and to acquire accurate conceptual understandings in a first-hand-, second-hand- or first-hand- followed by second-hand- investigation?"* Before elaborating, one reminder is warranted here. It should be noted that the counts and selections reported in Tables 4.2 and 4.3 do not reflect students' engagement with *accurate* conceptual claims during the *Engage* and *Prepare to Investigate* phases. As I have explained, accuracy was only taken into account when tallying a claim count during the *Prepare to Report/Report* phase[2]. It was then that students were expected to be achieving accurate conceptual understandings. But during the *Engage* and *Prepare to Investigate* phases, student engagement with any mass-motion and force-motion claims, whether accurate or inaccurate, was conducive to their ultimate arrival at accurate conceptual understandings.

An initial observation I made is that Ms. Allen instructed five of the six groups that displayed the richest opportunities for learning in terms of engagement with scientific practices and conceptual understandings. This first finding may suggest that Ms. Allen had more expertise in conducting inquiry-based science instruction, particularly in the modes of instruction that this study employed. However, this assertion must be tempered by the counterevidence demonstrated by my selection of lean cases. One of Ms. Allen's instructional groups was also chosen as a contrastive case displaying

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[2] In Appendices M and N, I report all the accurate and complete conceptual claims that were counted toward the claims scores for each instructional group during the *Prepare to Report/Report* phase of weeks 1 and 2. These claims are provided as a demonstration of the different ways that students accurately articulated their conceptual understandings.

the leanest opportunities for learning in week two's *Prepare to Report/Report* phase. This finding suggests that Ms. Allen, may not have been the sole factor accounting for the richness of opportunities for learning in the selections for rich cases.

A second look at the selections for richest cases also reveals that they were not only mostly taught by Ms. Allen but that, with one exception, they all featured second-hand investigation as the instructional mode. This finding suggests that the second-hand investigation instructional mode may have led to richer opportunities for learning. Of course, this assertion must be tempered by the argument that it is quite possible that the interaction between the particular students in Ms. Allen's second-hand investigation instructional group, the teacher herself, and the instructional mode were what together led to the richer opportunities for learning.

An examination of the leanest cases lends support to the assertion that second-hand investigation, whether part of the second-hand investigation or the interplay condition, may consistently lead to richer opportunities for learning. Apart from one exception, the lean cases all featured first-hand investigation as the mode of instruction. In addition, the lean cases featuring first-hand investigation were taught by two different teachers, suggesting that the lean opportunities could not be explained by the practices of a particular teacher alone. Also, there was only one instance where an instructional mode featuring second-hand investigation was selected as the lean case. That occurred in the second week of Ms. Allen's interplay condition.

Measures of Time Spent in Each Phase of Instruction

The macro-analytical video viewing also yielded measures of time that each instructional group spent in each phase of instruction. As I will describe, these measures demonstrated if the results reported above, with regard to differential opportunities for engaging with scientific practices and conceptual claims, were merely a manifestation of differential amounts of instructional time across instructional modes.

The study was designed with the intention that instruction would span 45-50 minutes per day of instruction for each instructional group, thus resulting in 225-250 minutes of instruction per week. However, there were slight variations upon these times based on logistics. For example, set-up required more time in some situations than others; and there were sometimes challenges associated with retrieving students from their home classrooms and bringing them all to the "laboratory" classrooms. These types of circumstances were unavoidable and sometimes resulted in groups receiving a few less or more minutes of instructional time than others.

It should also be noted that within these time frames, the amount of time that instructional groups spent *per phase of instruction* varied, depending on the demands of instruction in each individual situation. The most extreme example of this occurred in Ms. Baker's first-hand investigation group. In week one, Ms. Baker's group appeared not to have adequate time to complete the *Prepare to Report/Report* phase of instruction. Thus, Ms. Baker extended this phase of instruction into week two, borrowing from the time meant for the second topic of instruction. This resulted in her having a relatively greater amount of time for the first topic of instruction, motion across a horizontal plane, and a lesser amount of time for the second topic of instruction, motion down an inclined plane, relative to the other instructional groups. Other logistics led to Ms. Allen's Interplay group also having less time for instruction in week two, relative to other groups.

The measures of time that each group spent per phase of instruction during weeks one and two are reported in Tables 4.4 and 4.5.

Table 4.4
Minutes Spent per Phase of Instruction During Week One

Group	Engage	Prepare to Investigate	Investigate	Prepare to Report/Report	Total
First - Baker	6	127	56	65	254
First - Cannon	3	125	51	47	226
Second - Baker	11	62	0	160	233
Second - Allen	10	47	0	180	237
Interplay (First) - Allen	12	96	61	52	221
Interplay (First) - Cannon	5	116	54	54	229

Table 4.5
Minutes Spent per Phase of Instruction During Week Two

Group	Engage	Prepare to Investigate	Investigate	Prepare to Report/Report	Total
First - Baker	14	37	64	79	194
First - Cannon	15	38	72	92	217
Second - Baker	23	98	0	107	228
Second - Allen	32	81	0	128	241
Interplay (Second) - Allen	31	86	0	77	194
Interplay (Second) - Cannon	31	49	0	133	213

The measures reported in Tables 4.4 and 4.5 are useful for the purpose of noting that certain circumstances led instructional groups to have slightly varied total instructional times. However, what is perhaps more pertinent to responding to the first research question is the proportion of total instructional time that each group spent per phase of instruction. These proportions are reported in Tables 4.6 and 4.7 and displayed graphically in Figures 4.1 and 4.2.

Table 4.6
Proportions of Time Spent per Phase of Instruction During Week One

Group	Engage	Prepare to Investigate	Investigate	Prepare to Report/Report
First - Baker	2%	50%	22%	36%
First - Cannon	1%	55%	23%	21%
Second - Baker	5%	26%	0%	69%
Second - Allen	4%	20%	0%	76%
Interplay (Second) - Allen	5%	44%	28%	23%
Interplay (Second) - Cannon	2%	51%	23%	24%

Table 4.7
Proportions of Time Spent per Phase of Instruction During Week Two

Group	Engage	Prepare to Investigate	Investigate	Prepare to Report/Report
First - Baker	7%	19%	33%	41%
First - Cannon	7%	18%	33%	42%
Second - Baker	10%	43%	0%	47%
Second - Allen	13%	34%	0%	53%
Interplay (Second) - Allen	16%	44%	0%	40%
Interplay (Second) - Cannon	15%	23%	0%	62%

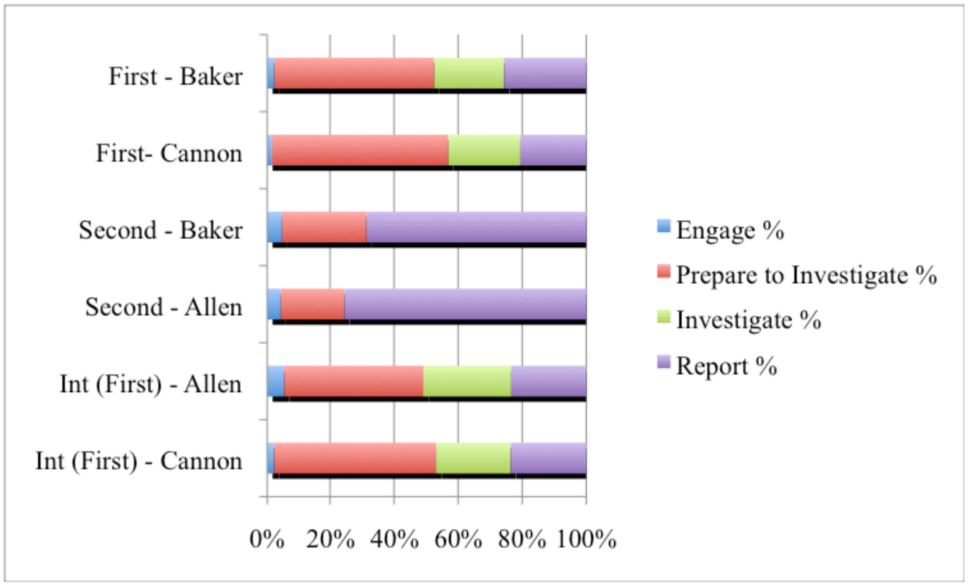


Figure 4.1. Proportions of time spent per phase of instruction during week one

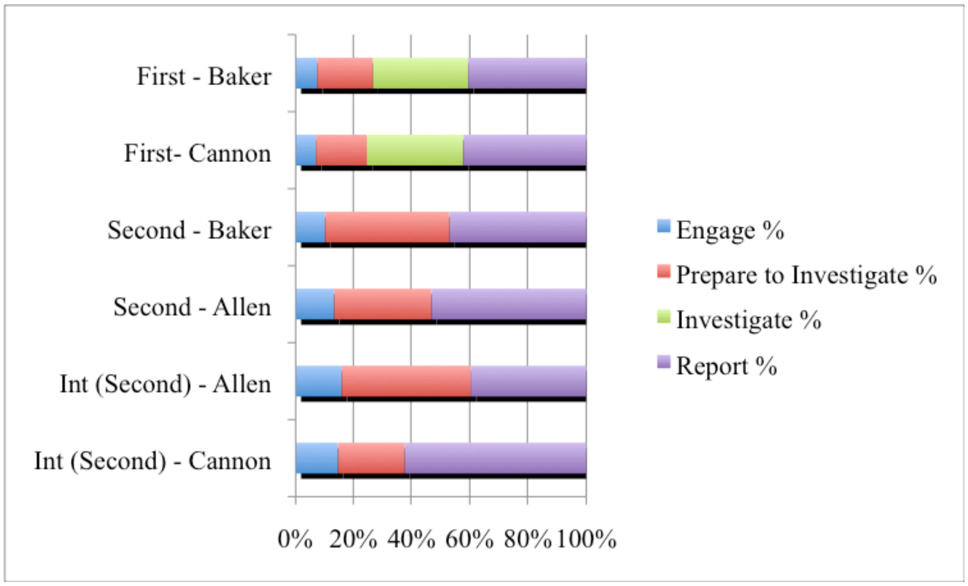


Figure 4.2. Proportions of time spent per phase of instruction during week two

As shown, instructional groups that featured the same mode of instruction tended to divide time amongst phases of instruction similarly. In week one, the interplay groups experienced first-hand investigation; thus, not surprisingly, the proportions of time they spent per phase of instruction were similar to the first-hand investigation groups. In week two, the interplay groups experienced second-hand investigation; thus, not surprisingly, the proportions of time they spent per phase of instruction were similar to the second-hand investigation groups.

The findings reported in Tables 4.6 and 4.7 and Figure 4.1 and 4.2 were generally responsive to the first research question, which asked, "*What opportunities do students have to engage in scientific practices and to acquire accurate conceptual understandings in a first-hand-, second-hand- or first-hand- followed by second-hand- investigation?"* The interpretations are obvious, at least at a superficial level. Clearly, when instruction featured first-hand investigation, teachers needed to segment the time available to allow for one additional phase of the inquiry cycle, the *Investigate* phase. This naturally allowed them less time for the other phases of instruction.

Variations in the way time was utilized across instructional modes were thus very clear. In week one, groups featuring first-hand instruction tended to spend a greater proportion of time preparing to investigate than the second-hand investigation groups; but they were left with less time to report upon their findings from their investigations. In contrast, students in the second-hand investigation groups spent most of their time in the *Prepare to Report/Report* phase.

However, in week two, groups involved in first-hand investigation appeared to almost "catch up" to the second-hand groups in terms of time spent in the *Prepare to Report/Report* phase. Of course, being that they still needed time to investigate, these groups had to compensate for the time gained in the *Prepare to Report/Report* phase by losing time elsewhere. This compensation occurred by spending less time in the *Engage* and *Prepare to Investigate* phases, relative to the groups featuring second-hand investigation. It is notable also that the groups featuring first-hand investigation spent much less time preparing to investigate during week two than week one. This change might be attributable to the procedural skills they had already gained in week one with regard to carrying out a first-hand investigation. Teachers may have felt it was not necessary to spend as much time preparing them to investigate in week two since they had already developed many relevant procedural skills during the prior week.

A critical reminder, as shown in the framework for this unit of instruction (see Table 4.1), was that the *Prepare to Report/Report* phase was the only phase whose instructional purpose was to lead students to an accurate conceptual understanding. Until this point, it was expected that students would be considering multiple explanations for the scientific phenomenon. But the *Prepare to Report/Report* phase was critical for solidifying an accurate understanding. Thus, in week one, instructional groups that engaged in first-hand investigation appeared to have less time available toward this purpose. This finding may at least partially explain how it is that the second-hand investigation instructional mode appeared to offer students richer opportunities for learning, particularly in the *Prepare to Report/Report* phase of week one. One could argue that it is critical for science instruction to lead students to complete and accurate conceptual understandings. If engaging students in first-hand investigations sacrifices the time allocated for students to engage in whole-group discussion around the purpose of developing accurate conceptual understandings, the tradeoff may be too severe to be worth the investigation experience.

But of course, there are multiple ways of interpreting this finding. One could also argue that indeed the “startup” costs of implementing instruction featuring first-hand investigation may be high. During initial implementation of this instructional mode, students may need high procedural support to prepare to investigate; and this would imply less time available for other purposes, such as engaging in whole-group discussion around conceptual claims during the *Prepare to Report/Report* phase. But as this two-week implementation of instruction featuring first-hand investigation has shown, the amount of procedural support for preparing to investigate would likely decrease over time – thus allowing more time for whole-group discussion around the results of the investigation and related conceptual claims. In other words, if the "startup" costs of implementing this type of instruction are quickly incurred, then it may leave ample time to reap the benefits of long-term implementation of instruction featuring first-hand investigation.

It has also been argued from a constructivist perspective (Loveless, 1998) that there is a critical advantage to students having the opportunity to generate claims based on knowledge they have constructed for themselves. Engaging in first-hand investigation may support students in appropriating knowledge because it is constructed through their own discovery. Thus, a study of longer term implementation of instruction featuring first-hand investigation could potentially show that students eventually reap rich benefits of *initially* engaging in high procedural support at the expense of opportunities for conceptually focused discussion.

In addition, one previously noted limitation of this study is that the research called for the video footage to follow the teacher. Thus, the video data did not audibly capture children's small group discussions during the *Investigate* phase of first-hand investigations. Due to this factor, my analyses could not account for those students' engagement with scientific practices and conceptual claims during the *Investigate* phase.

I assumed that this type of engagement would be captured in the whole group discussion during the *Prepare to Report/Report* phase. But to the extent that this did not happen, my analyses may not have fully captured children's engagement with scientific practices and conceptual claims during first-hand investigations.

With regard to opportunities to engage in scientific practices, as I have explained already, students could potentially engage in any scientific practice during any instructional phase. Thus, there were no differences in potential opportunities to engage in scientific practices across instructional modes.

Summary of Macro-analytical Findings

The results of the time-based analysis are somewhat ambiguous. They generally point to the conclusion that groups featuring first-hand investigation had less time to arrive at accurate conceptual understandings, especially in week one. But as I have discussed, over time it is possible that instruction featuring first-hand investigation would offer students richer opportunities for learning. It could also be argued that it was not necessary for students to spend so much time engaged in discussion about their findings because they had engaged in the investigations themselves and had independently come to accurate understandings, even with less time available for whole group discussion around their findings. Unfortunately, I was unable to attend to children's small-group discussions during the *Investigate* phase; and it was, therefore, not possible to determine the extent to which children conducting first-hand investigations during the *Investigate* phase were engaged with scientific practices and conceptual claims.

However, at least during the phases of instruction I did attend to, the frequency counts of scientific practices and conceptual claims that students engaged with suggest that instruction featuring second-hand investigation was consistently richer with opportunities for learning. The second-hand investigation mode and the interplay mode, when featuring second–hand investigation, tended to offer the richest opportunities for engaging with scientific practices and conceptual claims while the first-hand investigation mode tended to offer the leanest opportunities. Whether this finding is a manifestation of time available for particular phases of instruction or other characteristics of the instructional settings is unclear. The subsequent case study analyses, reported in Chapter 5, led to more clarity with regard to these issues. By examining what features of the instructional settings mediated the apparent richer learning opportunities present in the second-hand investigation instructional mode and the apparent leaner learning opportunities in the first-hand investigation instructional mode, the case studies revealed a greater understanding of differences across instructional modes.

CHAPTER 5: MICRO-ANALYTICAL FINDINGS

Overview of the Findings

This chapter presents the findings from a cross-case analysis of the three sets of micro-analytical contrastive case studies, each featuring a rich case and a lean case from week one and each corresponding to one of the phases from the GIsML inquiry cycle. Thus, the three sets of contrastive case studies were the following: *Engage* contrastive cases, *Prepare to Investigate* contrastive cases, and *Prepare to Report/Report* contrastive cases. Recall that the sets of contrastive case studies were selected based upon the results of the macro-analysis, which broadly uncovered the frequency counts of scientific practices and conceptual claims that students engaged with. Generally speaking, the cases that offered the most and least opportunities for such engagement were deemed the richest and leanest cases respectively. For the *Engage* phase, the set of contrastive case studies included Mr. Cannon's interplay group as the rich case (which featured first-hand investigation in week one) and Mr. Cannon's first-hand investigation group as the lean case. For the *Prepare to Investigate* phase, the set of contrastive case studies included Ms. Allen's second-hand investigation group as the rich case and Mr. Cannon's first-hand investigation group as the lean case. For the *Prepare to Report/Report* phase, the set of contrastive case studies included Ms. Allen's second-hand investigation group as the rich case and Ms. Baker's first-hand investigation group as the lean case.

The case studies were designed to respond to the second research question, which asked, "*What mediates the learning opportunities for engaging with scientific practices* *and acquiring accurate conceptual understandings across and within conditions?"* In response to this research question, my findings showed that there were two points of mediation for children's opportunities to engage with scientific practices and conceptual understandings. First, there were several characteristics of the first-hand investigation and second-hand investigation instructional modes that served to either enable or constrain children's learning opportunities. Secondly, teachers largely mediated children's learning opportunities by utilizing specific practices or discourse moves that served to enact the curricula in distinctive ways. This finding was reminiscent of the claim asserted by Brown and Edelson (2003) that teachers necessarily bring curricular attributes to life in unique ways. Thus, the two points of mediation that my study revealed, characteristics of the instructional modes and teacher moves, were closely linked. My findings highlight these linkages.

There are two caveats that should be acknowledged with regard to my findings. First, I am not able to report on the data that included when children were engaged in data collection during the *Investigate* phase. One might hypothesize that the time children spent during the *Investigate* phase of the first-hand investigation instructional mode would be a very rich opportunity to engage with scientific practices and conceptual understandings. Nevertheless, as I have noted already, the research called for following the teacher during the small group work rather than students. This prevented me from attending to and analyzing the potential learning opportunities that students were engaged in during the *Investigate* phase. It is important to recognize that this limitation of the dataset skewed what it was possible for me to study and thus for my analyses to reveal. In fact, as I reported in Chapter 4, two of the three rich cases that I identified and analyzed featured second-hand investigation (the rich cases for the *Prepare to Investigate* and the *Prepare to Report/Report* phases); and in the remaining set of contrastive cases (for the *Engage* phase), there was actually no difference in the instructional mode, as they both featured first-hand investigation, and they were also very short in duration. Thus, my cross-case analyses tended to reveal affordances of the second-hand investigation instructional mode and the way that they mediated learning opportunities for students.

Secondly, as I have noted in Chapter 3, I again acknowledge that the case study analyses did not attend to instruction during week two. I based this decision on the fact that the conceptual terrain was unique across the conditions, thus precluding a close comparative analysis of learning opportunities in week two. As a result, the case study analyses did not illuminate particular affordances and challenges associated with the interplay instructional mode. The unique characteristic of the interplay condition was that an initial week of instruction featuring first-hand investigation was followed by a week of instruction featuring second-hand investigation. But of course, this attribute of the instructional mode was not manifested until the second week of implementation.

Chapter Organization

In the following sections of this chapter, for each set of contrastive cases, I first explain the selection process that led me to determine which cases were richest and leanest with opportunities for engaging students with scientific practices and conceptual claims for that phase of instruction in detail. I also report which segments of instruction I transcribed and analyzed.

Then, I report the main findings that were revealed via the cross-case analyses. As I have described in detail in Chapter 3, I engaged in these cross-case analyses utilizing three analytical lenses: a participant structure lens, a connections to prior experiences lens, and an argumentation lens. Thus, I report my findings using these analytical lens, acknowledging that these lenses are often in interplay.

Case Selection Determinations

The Engage Contrastive Cases

The richest example of the *Engage* phase in week one was Mr. Cannon's interplay group, featuring first-hand investigation. The leanest example was Mr. Cannon's first-hand investigation group. Thus, in this set of contrastive cases, both the rich and lean case featured the same instructional mode and the same instructor, Mr. Cannon. These constants allowed for a narrower focus on teacher moves in relation to two sets of students.

For the rich case, Mr. Cannon's interplay group (featuring first-hand investigation), instruction summed to 5 minutes, during which time students engaged with no scientific practices and made 8 claims that were related to mass- and force-motion relationships. I also considered Ms. Allen's interplay group (featuring first-hand investigation) in determining the richest example of week one's *Engage* phase. However, for this group, Ms. Allen's instruction summed to approximately 12 minutes, during which time students also engaged in no scientific practices but made 8 claims that were related to mass- and force- motion relationships. In other words, Mr. Cannon's group engaged with an equal number of practices and claims as Ms. Allen's group in less than half the time. So while Ms. Allen's instruction did seem to offer students many opportunities for learning scientific literacy, Mr. Cannon's interplay group appeared to be the richest. It should be noted that this was the one phase in which all the instructional groups engaged in either zero or one scientific practices. Thus, I did not consider a balance between engagement with practices and claims as a critical factor in determining contrastive cases.

The leanest example of the *Engage* phase in week one was Mr. Cannon's first-hand investigation group. For this group, instruction summed to approximately 3.5 minutes, during which time students engaged in no scientific practices, and made 4 scientific claims that were related to mass- and force- motion relationships. The small number of claims made by students was the critical factor that led me to identify it as the leanest example for providing students with opportunities for learning scientific literacy. There were two other instructional groups (Ms. Baker's first-hand investigation and Ms. Baker's second–hand investigation) that were nearly as lean. In those groups, students engaged with only one more claim than students in Mr. Cannon's first-hand investigation group. However, I observed one other factor that seemed to contribute to the leanness of opportunities for learning in Mr. Cannon's first-hand investigation group. Only two students participated in making the 4 conceptual claims. In other words, in addition to the leanness demonstrated by the small number of claims, there was low student participation in Mr. Cannon's first-hand investigation instructional group in week one's *Engage* phase.

Due to their short length, I transcribed the entire *Engage* phase of instruction for both the rich and lean cases (approximately 5 and 3.5 minutes respectively). Transcripts for these segments are provided in Appendices O and P. As described in Chapter 3, I tracked assertions that I derived during my analyses in a table. I juxtaposed related assertions across the set of contrastive cases and listed assertions singly when their was no related assertion for the contrasting case. These tables are provided in Appendix L.

The Prepare to Investigate Contrastive Cases

The richest example of the *Prepare to Investigate* phase in week one was Ms. Allen's second-hand investigation group. The leanest example was Mr. Cannon's first-hand investigation group. Ms. Allen's *Prepare to Investigate* instruction for her second-hand investigation group spanned across two days and summed to approximately 50 minutes, during which time students engaged with three scientific practices and made ten claims that were related to mass- and force- motion relationships. Before making this determination, I also considered two other instructional groups, Mr. Cannon's first-hand investigation group and Ms. Baker's first-hand investigation group. In these two groups, students engaged with a greater number of scientific practices but with fewer claims (relative to Ms. Allen's second-hand investigation group). However, both groups spent over double the amount of time in week one's *Prepare to Investigate* phase (approximately 125 and 127 minutes respectively) as compared to Ms. Allen's 50 minutes. I decided that for such a long time span, there were very few scientific claims that students made in comparison with the relatively large number of scientific practices in which they engaged. So while Mr. Cannon and Ms. Baker's first-hand investigation instruction did seem to offer students many opportunities for learning scientific literacy, particularly for engaging with scientific practices, Ms. Allen's second-hand investigation group did appear to be the richest given the amount of opportunities offered within a much shorter time.

Unfortunately, the *Prepare to Investigate* phase in the first week of instruction was the only instance where missing data affected my choice of contrastive cases. There were two damaged tapes, one for Ms. Allen's and one for Mr. Cannon's Interplay groups.

It appeared that the instruction on both of these tapes was during the *Prepare to Investigate* phase, both occurring for instruction on October 21, 2003. For both groups, the remaining instruction for the *Prepare to Investigate* phase occurred on other days and was therefore observed on other tapes. On those tapes, I observed that children were engaged with several scientific practices but that children did not make any scientific claims. Thus, this lack of balance between children engaging in scientific practices and children making scientific arguments for both of these groups could potentially have led them to be exemplars of lean cases. However, since a significant amount of data was missing, I felt it was not justifiable to make a selection from those cases.

Thus, I chose the contrastive case for the leanest example of the *Prepare to Investigate* phase from the remaining instructional groups. I determined that Mr. Cannon's first-hand investigation group was the leanest available example. For this group, instruction spanned across four days and summed to approximately 125 minutes, during which time students engaged with seven scientific practices, but only made one scientific claim that was related to mass- and force- motion relationships. The small number of claims made by students was the critical factor that led me to identify it as the leanest complete example (with no missing data) for providing students with opportunities for learning scientific literacy.

For the rich case, Ms. Allen's second-hand investigation group, I transcribed approximately 16 minutes of instruction that occurred on October 21, 2003. This segment was representative of the types of activities and focus throughout the group's *Prepare to Investigate* phase of instruction. For the lean case, Mr. Cannon's first-hand investigation group, I transcribed approximately 34.5 minutes of instruction that occurred on October

20, 2003, approximately 5 minutes of instruction that occurred on October 22, 2003, and approximately 4.5 minutes of instruction that occurred on October 23, 2003. It was necessary to transcribe this greater length of video for the lean case because discussions often spanned a longer time before moving onto a new topic. These segments were representative of the types of activities and focus throughout the group's *Prepare to Investigate* phase of instruction. Transcripts for these segments are provided in Appendices Q and R. As noted, Appendix L also contains the table where I tracked assertions that I derived from my analyses for the set of contrastive cases.

The Prepare to Report/Report Contrastive Cases

The richest example of the *Prepare to Report/Report* phase was Ms. Allen's second-hand investigation group. The leanest example was Ms. Baker's first-hand investigation group. As noted already, in this phase of instruction, only accurate claims that accounted for both mass-motion and force-motion relationships were counted toward the claims score. A list of the accurate claims is provided in Appendices M and N. For Ms. Allen's second-hand investigation instructional group, the *Prepare to Report/Report* phase spanned across four days and summed to approximately 180 minutes. During this time students engaged with nine scientific practices and made five accurate claims that integrated both mass-motion and force-motion relationships. These frequencies were higher than for any other instructional group for both scientific practices and conceptual claims. In fact, no other group engaged with more than two accurate and complete conceptual claims.

The leanest example of the *Prepare to Report/Report* phase in week one was Ms. Baker's first–hand investigation group. For this group, instruction spanned across two days and summed to approximately 65 minutes, during which time students engaged with five scientific practices but made no accurate claims that integrated both mass-motion and force-motion relationships. The fact that students posed no accurate claims that integrated both mass-motion and force-motion relationships distinguished this group from all other groups. This was the critical factor that led me to identify it as the leanest example for providing students with opportunities for learning scientific literacy.

Ms. Baker's first-hand investigation instructional group was also distinguished by the fact that Ms. Baker extended the *Prepare to Report/Report* phase of instruction into week two, borrowing from the time meant for the second topic of instruction. She appeared to make this decision based on the fact that students had only had enough time to just begin reporting their results in week one. Nevertheless, despite this extended time, students in this group engaged with no accurate and complete conceptual claims.

For Ms. Allen's second-hand investigation group, I transcribed approximately 19.5 minutes of instruction that occurred on October 22, 2003, 7 minutes of instruction that occurred on October 23, 2003, and 14 minutes of instruction that occurred on October 24, 2003. These segments of instruction were representative of the different types and focus of learning activities that students engaged. For the lean case, Ms. Baker's first-hand investigation group, I transcribed approximately 16 minutes of instruction that occurred on October 24, 2003 and approximately 17 minutes of instruction that occurred on October29, 2003. These segments of instruction were representative of the different types and focus of learning activities that students engaged. Transcripts for these segments are provided in Appendices S and T. As noted, Appendix

L also contains the table where I tracked assertions that I derived from my analyses for the set of contrastive cases.

Participant Structure Lens

The Instructional Mode as a Point of Mediation for Learning Opportunities

Broadly speaking, science instruction that engages children in first-hand investigations is believed to potentially position them as being knowledgeable and capable of producing knowledge. Palincsar and Magnusson (2006) hypothesized that first-hand investigations provide critical opportunities for learners to try out and test their thinking and to develop scientific understandings about the physical world. Such a position would be consistent with a constructivist perspective on learning (Loveless, 1998). My cross-case analyses were based on a close study of only three sets of contrastive cases; and therefore they cannot justifiably confirm or refute such a claim. However, my analyses do serve to complexify this hypothesis by highlighting affordances associated with engaging children in second-hand investigations and challenges associated with engaging children in first-hand investigations. Importantly, the main finding related to characteristics of the instructional modes that was elicited from the participant structure analytical lens was that it is also possible to position children as "knowers" or knowledge creators through the use of texts that engage them in second-hand investigations.

The notebook text utilized in this study made the thinking processes of a fictitious scientist, Lesley, transparent to young learners. The notebook text also portrayed Lesley as a capable thinker who still could be vulnerable to making errors or incorrect predictions. This is shown, for example, in the very first paragraph of the notebook text:

Excerpt 1 (taken from notebook text, week 1, p. 1)

I was biking with my friends when Felicia challenged us to a race to the park. Jermaine, who is very large and muscular, shouted that he was going to win because his strong legs would make the bike go fast once he got it going. Felicia, who is tall and slender, replied that she was going to win because she was light and her long legs would make her pedaling strong. I thought I might win because I would not weigh down the bike like Jermaine, and I could push the bike harder than Felicia because I can pedal faster with my shorter legs. To my surprise, we all got to the park at the same time! How could that be?

With Lesley's thinking processes laid bare, students potentially had opportunities to evaluate her thinking or to engage in parallel thinking processes. These characteristics of the notebook text mediated children's opportunities to engage with scientific practices and conceptual claims, because they enabled the possibility that a learner could "participate" in similar thinking processes as Lesley or evaluate her thinking.

The notebook text featured Lesley as she shared her experience of conducting a scientific investigation, from the initial steps of reflecting upon the scientific phenomenon, through the setup of the investigative model and the process of data collection and interpretation, and until her engagement with claim generation. All of these aspects of the notebook text afforded the possibility that children could engage in thinking processes that parallel the inquiry experience through a second-hand investigation.

Teacher Moves as a Point of Mediation for Learning Opportunities

However, though the notebook text provided the content with which children could engage in a participatory fashion, the text itself did not provide them with a means for doing so. Ms. Allen brought the affordances of the text to life in two ways: by designing learning activities that approximated the experience of conducting a scientific investigation and by utilizing discourse moves that positioned students as being knowledgeable.

Designing Participatory-based Learning Activities

I elaborate first on the way that Ms. Allen mediated children's learning opportunities by designing learning activities that engaged them in a participatory use of the notebook text. These activities appeared to approximate the first-hand investigation experience. For example, on the first day of the *Prepare to Report/Report* phase, students read about Lesley's investigation and reviewed the data she had collected in Table 1 of the notebook text (shown in Appendix F). Ms. Allen then guided her students in interpreting the meaning of the various cells of Table 1. One example of this was that she guided students in noting that when the mass was 1 block and the force was 1 washer, the first trial showed that the cart took 1.32 seconds to travel across the board.

On the next day, Ms. Allen supported students in illustrating any one trial of their choosing. Before they made their illustrations, she helped them identify the critical variables they would need to illustrate per trial. Thus, even though students had not conducted first-hand investigations themselves, Ms. Allen facilitated activities that enabled students to participate in Lesley's investigation by visualizing it and attending closely to the data. Ms. Allen then asked the students to come up to the overhead projector, reproduce their drawings and write the time that it took the cart to travel across the board. This move served to empower students by allowing the illustrator to call on other students to identify the trial number that the illustration depicted. In other words, even though the data came from Lesley's notebook, Ms. Allen released authority to the students by placing them in a teacher-like position of knowledge and power. The students themselves had the authority to call upon their peers to respond to their questions. Thus, while her students may not have had the direct experience of engaging in a scientific investigation, Ms. Allen was able to approximate this experience through simulated investigation activities based upon the notebook text, such as those involving illustration and data interpretation.

Other researchers have pointed to multiple benefits of releasing authority to students in inquiry-based science instruction. Ballenger (1997) described science talks where bilingual middle school-aged students discovered and questioned characteristics of mold and then proceeded to spontaneously suggest experiments that would demonstrate the conditions under which mold grows. Ballenger explained how this feature of classroom instruction shifted traditional power roles: “When the questions came from the students, the teachers were often hard-pressed to fully understand the question. They had to turn to the questioner as the expert who had the opportunity to elaborate: thus the location of knowledge shifted from teacher to student in these instances” (p. 11). Like Ms. Allen’s instruction, this shift also led students to direct their comments and questions to each other instead of always addressing their comments to the teacher. Engle and Conant (2002) similarly found that placing students in positions of authority led them to take on more responsibility for conducting an inquiry.

Utilizing Discourse Moves that Positioned Students as “Knowers”

In addition to the learning activities that Ms. Allen designed, she utilized the following types of discourse moves that positioned students as being knowledgeable and as having ideas that were valuable: (1) by associating ideas with the names of the students who generated them and by giving students opportunities to confirm that she was representing their ideas correctly; (2) by encouraging students to evaluate the conceptual rationale for Lesley's engagement with particular scientific practices; (3) by equating students with professional scientists or mathematicians; and (4) by performing procedures before reading about Lesley's performance of those procedures. I elaborate further on each of these type of discourse moves.

When Ms. Allen paraphrased what students said or asked them to elaborate upon their own or each other's ideas, she referred to their ideas by name, for example by naming an idea "Bethany's thinking." She also tended to check back in with students to make sure she was correctly portraying their ideas, as shown in *Excerpt 2.*

Excerpt 2

Ms. Allen: What do you suppose when we look at her notebook and see the page where she has her data, what do you think the information will look like? What information will she have to give us? So let's reread the description and see what should be there. Leonard?
Leonard: I think that um like she should have the weight of the person, the person, the time.
Ms. Allen: OK. So you're thinking that there's going to be information about the weight. And how is she varying the weight? What is she using as a to represent weight. Let me hear from some of our young ladies.
Bethany: Um the blocks.
Ms. Allen: She's using the blocks. So Leonard is it okay if I say that she should have the number of blocks?
Leonard: Mm hmm.
Ms. Allen: OK. Number of blocks that she's investigating with.

Ms. Allen consistently engaged students in this way, appropriating their ideas by giving them the opportunity to affirm the way their ideas should be worded. These actions were similar to practices utilized by Lampert (1990). For example, Lampert described her common practice of writing student solutions to math problems on the board for the class to consider. Furthermore, she had a tendency to write the students' names next to their answers in order to facilitate interaction amongst students and student ideas.

In contrast, when Mr. Cannon collected ideas from his students, he frequently modified the wording they used when he paraphrased their oral speech and wrote their idea on a projected transparency. He also did not check with the student when making such changes. Mr. Cannon also tended to dismiss student ideas when they were incorrect without discussing why they might be wrong. Thus, those ideas seemed to vanish from the dialogue altogether, instead of being acknowledged as coming from a student, whether right or wrong. *Excerpt 3* provides such an exemplar. It is taken from a discussion during which Mr. Cannon collected ideas from the students with regard to what objects from the bike race would need to be modeled for the investigation.

Excerpt 3

Mr. Cannon: Anything else? Levi?
Levi: Same bike tires?
Mr. Cannon: Ah. OK. OK. Let's just put tires right here (writing). Tires. Anything else?
S: Handlebars
Mr. Cannon: Well, those are all parts of the bike. What were the people doing to the bike?
S: Riding.

The excerpt shows first that Mr. Cannon paraphrased Levi's words, "same bike tires" as "tires" without discussing if Levi had intended for a more specific meaning to be conveyed by the words "same bike tires." In the next exchange, Mr. Cannon dismissed a student's idea that the handlebars should be included in the investigation without fully explaining why the idea was unfitting. During the preceding discussion, the group had already established that the model would need to include an object to represent the bike, and so Mr. Cannon responded in a truncated form that the idea of "handlebars" had already been incorporated into the model since the bike was already included ("Well, those are all parts of the bike."). However, no such explanation was provided to the student who suggested that handlebars should be included in the model. Instead, Mr. Cannon dismissed the student's idea ("Well, those are all parts of the bike.") and moved on ("What were the people doing to the bike?"). These actions conveyed a lack of regard for students because their ideas were readily modified or dismissed by the instructor. They also appear to implicitly contrast with recommendations given by many researchers (Ballenger, 1997; Engle & Conant, 2002; Lampert, 1990) who argue that students should be imbued with some decision-making authority in inquiry-based instruction.

The second type of discourse move that Ms. Allen used was that she engaged students in considering the conceptual rationale behind Lesley's scientific practices and claims. Thus, student thinking was at the forefront of all discussion, and students were positioned as being knowledgeable in that they were evaluating Lesley's thinking. For example, *Excerpt 4* features Ms. Allen's students during the *Prepare to Investigate* phase involved in a discussion around modeling the investigative phenomenon and what they believed Lesley would need to included in the model of the phenomenon.

Excerpt 4:

Ms. Allen: What else is going to be there we hope? The time it took for the cart to get to the end (writing on poster paper). Please Renee.
Renee: Um. Maybe the number of washers and how big they were.
Ms. Allen: Alright. Excellent. So, the number of washers. When you say how big they get, I'm not sure I understand. Can you say some more about that?
Renee: If um if they were like really small ones like about that big, then write like how big they were and how small they were.
Ms. Allen: OK. Alright. That's an interesting point you're raising. Let me ask you this. Do you think that she should be changing the size of the washers? Leonard says yes. Aaron says no. Thalia says yes. So let's talk a little bit about this. Leonard what's your thinking?

Leonard: I think like um I think Jermaine might have to change. 'Cuz he has muscular legs but yet he has long legs. So that would be like a that would be like a minor set back. And then like Felicia she has short legs so it might take her longer to pedal. But it would be easier for her to pedal because she has short legs and she doesn't have to with big bikes go up and down the whole time.
Ms. Allen: Alright. That's interesting. Aaron you don't think that she has to change the size of the washers. What's your thinking?
Aaron: Because if you change them you have all different measurements.
Ms. Allen: OK. OK. So you're saying she better keep the size of the washer the same. Otherwise we have yet another variable. I want to get back. Let me hear from Thalia first and then Leonard I want to return to your thinking about whether the leg size. And I actually want I actually want all of you to be thinking about this issue, because it's a very interesting one.

Ms. Allen initially asked simply "What else is going to be there we hope?" (in Lesley's model of the biking event). However, after Renee responded that the model should include the number of washers and their size, Ms. Allen probed her to elaborate upon her thinking. This initiated a discussion amongst the students during which they made multiple kinds of comments. Leonard integrated his thinking about the need to change the size of the washers with his conceptual claims about mass-motion and force-motion relationships. Aaron spontaneously engaged the students in another scientific, considering the systematic manipulation of variables. In this way, dialogue in Ms. Allen's group moved fluidly between engaging in scientific practices in service of scientific content. Importantly, the students' conceptual thinking was always at the forefront of discussion.

In contrast, Mr. Cannon's first-hand investigation instructional group was largely engaged in considering only the procedural aspects of setting up the investigation. An example of this is shown in *Excerpt 5,* where Mr. Cannon explicitly demonstrated the investigative setup to the students and helped them to record, in a somewhat rote manner, the objects that would be used to represent each aspect of the biking phenomenon on a worksheet.

Excerpt 5

Mr. Cannon: In the model of the race, we need to think about what materials we can use. So the second column here the model of the race. We're gonna start thinking about what of these materials, which of these materials will we use to model that part of the race. So let's start with the bike. What of these materials will be
S: the bike.
Mr. Cannon: The bike?
S: The wheels.
Mr. Cannon: Okay. The wheels. In this case, we'll call it a cart. So this will be a cart (writing). That's C-A-R-T. OK. Oh and I gotta go get this part (goes to get ramp). The flat surface. Ahhh. The flat surface will be the board. Alright. And I'll ah…just set it right here for the time being. (writing) Alright…the board. I'm gonna get myself a table up here. (Moves table.) OK. Let me put this up like right like here. Here we go. OK. So that's our board. OK. People? What from these materials will be the people?
S: The blocks maybe.
S: The blocks.
S: The washers.
Mr. Cannon: The blocks. And where will we put the blocks?
S: On that.
Mr. Cannon: Okay. We could put the blocks on the cart. Ok. And that would. OK. Alrighty? Tires. Does the cart have tires?
Ss: Yeah.
Mr. Cannon: So that stays the same. So that's just tires.

Presumably, as these students were in a first-hand investigation instructional group, Mr. Cannon felt the need to clearly demonstrate the investigative setup to the students because they would need to set up the model themselves. This may be a challenge associated with the first-hand investigation instructional mode, as teachers need to prepare students for the actual procedural conduct of the investigation. However, the practices that Ms. Allen utilized to engage her students in considering the conceptual rationale for the investigative setup could certainly be applied to instruction featuring first-hand investigation. For example, in the first-hand investigation instructional mode also, teachers might ideally ask students why certain parts of the investigative phenomena would best be modeled in particular ways.

The *Prepare to Report/Report* contrastive cases also provided several examples of how Ms. Allen's students constantly considered the conceptual basis for Lesley's engagement with scientific practices, thus placing student ideas at the forefront of discussion. For example, this occurred prior to the students' reading of page 2 in the notebook text (see Appendix F), where Lesley describes the Tukey procedure. The Tukey procedure is a method of summarizing data that involves first eliminating the smallest place value digit for each entry in a set of data and then identifying the median value. Before students read the paragraphs about this procedure, Ms. Allen engaged them in thinking on their own about why there might be variation in the data that a scientist collects and then in suggesting their own methods for determining what the representative value of a set of data ought to be. Students contributed many of their own ideas in these discussions, as shown in Figure 5.1.

Student Ideas for why there is Data Variation	Student Ideas for Methods to Determine a Representative Value
Renee: …if she had put it at the one spot and then when down there to grab onto the washers, it might have rolled. Because when sometimes when something that is circle, you put it down and it'll roll. So she needed somebody else to hold the cart in its spot. And she was way down there. **Thalia**: I think that maybe she either did it too, she didn't do it the same distance or um …that's all. **Leonard**: When I said um two reasons why she could have timed it wrong yesterday. One of the reasons is like Thalia that um, in the picture it does show like about that much of the string hanging down. And um, when she did like it a second, third, or fourth or fifth time she could have pulled it all the way back and that would have been a different distance. Or she could have pulled it more up…. And then another thing is that she could have timed it wrong because it's a really hard thing to do when you're timing hundredths or tenths of a second. **Sam**: She might have accidentally like knocked the table so it went forward a little…. Or she might have given it a push some other time…. Or somebody might have - like if she had a little brother. **Lawrence**: Like Sam said, she might have had a little brother. And her little brother might have tripped and fell on the table.	**Leonard**: … Because um there is two times that are have like 130 or in the 130s. And then there is three times in the 120s. So it's most likely gonna be a 120. And you have a 127, a 123 and a 125. And so, what's in between the 123 and the 127 is 125. So that might be the most accurate um time that it took for the cart to get to the end. **Bethany**: It might be 1.23 and a half…. Because um it's just one time away from 1.24….So I figure, if you just try to divide those in two you'd get 1.23 and a half.

Figure 5.1. Student ideas about data variation and representative values

As shown, many of Ms. Allen's students demonstrated an understanding that there were several reasons for data variation; and they therefore saw the conceptual need for identifying one value that could be representative of all the data collected in a set of trials. As shown, student thinking was at the forefront of the discussion, well before they had read about Lesley's or Tukey's ideas. By collecting student thinking about these topics before they read about Lesley's thinking, Ms. Allen positioned the students as very capable thinkers who were not dependent upon the notebook text for ideas. These practices were again reminiscent of practices utilized by Lampert (1990, 2001), who purposefully assigned students problems, but did not provide procedures for solving those problems. Students were responsible both for crafting a strategy for solving the problem and for finding the solution:

> The intellectual problem for the students is to develop a mathematically legitimate strategy for finding the answer to a question posed by the teacher. The content of the lesson is the arguments that support or reject solution strategies rather than the finding of answers. Students' strategies yield answers to teachers' questions, but the solution is more than the answer, just as the problem is more than the question. Generating a strategy and arguing for its legitimacy indicates what the student knows about mathematics. (p. 40)

Ms. Allen's instruction similarly engaged students in intellectually developing a mathematical strategy that would demonstrate their understanding of the conceptual issue at hand.

After the students finally read page 3, Ms. Allen utilized a third type of discourse move to position students as "knowers." As shown in *Excerpt 6*, she drew parallels between Tukey's thinking and Leonard's thinking, thus suggesting that the students were just as capable as the scientific thinkers depicted in the notebook text.

Excerpt 6

Ms. Allen: And this is interesting, because - Do you remember when Leonard said it's very hard to get an accurate measure to the hundredths of a second? That's exactly what Tukey thought too. And so he said, you know what, since that's likely to be the least accurate, let's just lose it.

By reflecting on Tukey's method in this way, Ms. Allen equated Leonard to Tukey, enabling the students to see themselves as capable of thinking like mathematicians. In other circumstances, Ms. Allen similarly made connections between student thinking and Lesley's thinking, who was portrayed in the notebook text as a scientist.

Finally, after an extended discussion around both the conceptual rationale for the Tukey procedure and the procedural method for performing it, Ms. Allen engaged students in identifying representative values from Lesley's data using the Tukey method. They performed the method once together as a class and then once independently in their notebooks with the next set of trials. On page 3 of the notebook text (see Appendix F), Lesley reports a summary table that contains only the representative values obtained via the Tukey procedure. However, again, students did not read this page of the text until they had had a chance to perform the Tukey procedure themselves. This again served to position them as scientific thinkers who were as capable as Lesley in conducting the Tukey procedure.

Ms. Baker engaged her students in a series of activities that contrasted starkly with those depicted above. After students had completed the *Investigate* phase, they turned in their data to Ms. Baker at the end of class. She reviewed their data, copied them onto a new table, and circled the median of each set of trials herself. The following day, she passed the tables she had rewritten with the identified medians back to each student group. Unlike Ms. Allen, Ms. Baker did not engage the students in considering why there was variation in their data nor in designing their own methods for identifying a representative value of a set of trials. Her explanation of the process began with posting an example on the overhead projector. The example showed Shelly and Ellie's data with the medians already circled. Then, as shown in *Excerpt 7,* she simply told the class that she had circled the middle number and gave an explanation for how she identified that value. She then followed this brief explanation with engaging the class in confirming the values that she had already circled.

Excerpt 7

Ms. Baker*:* OK. In each of these cases, we have 5 trials. And so I looked at the numbers, and I said which is the middle number? Which is the middle number? So here, the lowest number is 0.78. And then the next number after that is which one? Sid, Dion, get your eyes up here. The lowest time is 0.78. Which time is next? Who can help? Kiely?
Kiely: 0.84.
Ms. Baker: 0.84 is next. What time is next highest? Mira?
Mira: 84.
Ms. Baker: That's what she just said is next. That's second. This is the lowest. Then this is the next high. Someone besides Kiely? Sid and Dion?

As shown, students did engage in identifying middle values of sets of trials from Shelly and Ellie's data, but only as confirmation of the work that Ms. Baker had already done for them. Unlike Ms. Allen's students, they did not consider the conceptual basis for engaging in this practice. This type of teacher move did not convey to students that they were scientifically capable thinkers in the way that Ms. Allen's actions did. But again, the practices that Ms. Allen utilized to engage her students in considering the reason there might be variation in one's data, in devising methods for identifying a representative value, and in conducting the actual procedure of independently identifying median values could certainly be applied to instruction featuring first-hand investigation. For example, in the first-hand investigation instructional mode also, it is conceivable that teachers might ask students why they believed there was variation in the data and how one should go about identifying a representative value, instead of only engaging students in confirming the teacher-determined medians.

Connections to Prior Experiences Lens

The Instructional Mode as a Point of Mediation for Learning Opportunities

Both the first-hand investigation and second-hand investigation instructional modes potentially afforded the opportunity for children to make connections with prior experiences. As I have described in Chapter 3, both instructional modes engaged students in considering hypothetical bike races between riders of varying physiques. Since children typically have had experience riding bikes, it would seem conceivable that, given certain instructional supports, children in both instructional modes could have constructed new understandings of mass-motion and force-motion relationships based upon their prior experiences. Interestingly, however, my analyses of the lean cases did not uncover any instances of children making connections to prior experiences. There was one example of a child who made a connection to a prior experience during the *Engage* phase rich case featuring first-hand investigation in Mr. Cannon's interplay instructional group, but the connection was very briefly referred to and not built upon. Thus, I believe that both instructional modes had a similar or even equal potential to mediate children's engagement with scientific practices and conceptual claims by facilitating connections to their prior experiences; but, as it turned out, this only substantively occurred in the rich cases that featured second-hand investigation.

Teacher Discourse Moves as a Point of Mediation for Learning Opportunities

Ms. Allen mediated children's engagement with scientific practices and conceptual claims by utilizing two types of discourse moves that enabled children to build upon their prior experiences: (1) by facilitating a connected discourse where children were invited to weigh in on each other's assertions; and (2) by using elicitation techniques to help children elaborate and construct upon those experiences. I elaborate on each of these types of discourse moves.

Ms. Allen frequently invited children not only to consider Lesley's thinking but also to comment on assertions posed by peers. In this particular instructional group, one student, Leonard, repeatedly asserted that a person's leg length is what determines his/her speed while bike racing. By asking students to weigh in on Leonard's assertion, Ms. Allen gave students an opportunity to formulate their own opinions. Sometimes, this appeared to motivate children to reflect upon their prior experiences as a standard against which to evaluate Leonard's assertion. One example of this is shown in *Excerpt 8,* where Renee responded to Leonard's assertion.

Excerpt 8

Ms. Allen: Now Leonard say a little bit more about your thinking about the size of the legs. And I'm curious to know what the rest of you have to say about that.

Leonard: Like um I'd have to say that like…The reason why she should really change the washers it's because like say if you had 3 blocks on it for Jermaine and 3 washers on the string. It would like take so much to get to the end. And if you kept three washers on. And you go to like. Say if Felicia was the lightest and she had only one block. That would make a that would make her faster and it wouldn't be a tie between Jermaine and Felicia.

Ms. Allen: Oh! You're starting to make some predictions about what her data will say. Very very interesting. Well, Let me see if there are any other issues that I think we should talk about with this paragraph before we look at those data and see whether your prediction is accurate. Renee?

Renee: Well um, when Leonard was saying that uh Felicia would….Um since she had long legs that it would take a little bit longer. But um I used to race around the block or at some point with my friend. And I would be taller but the bike he had bigger wheels. So if I pedaled faster um he'd win.

This excerpt suggests that Ms. Allen may have supported Renee in accessing this prior experience simply by asking her to consider Leonard's idea.

A similar incident occurred moments later when Sam weighed in on Leonard's assertion. This is shown in *Excerpt 9*.

Excerpt 9

Ms. Allen: Let me press on a little bit further with Leonard's idea. I'm curious, how many of you…Could you just show me by a show of hands? How many of you think that the length of the person's legs is something that will make a difference? So 1, 2, 3, 4, 5, 6,
S: Everybody!
Ms. Allen: 7, 8, 9. Everybody thinks that the length of the legs. In what way will make a difference? Go ahead Bethany.
Bethany: Because sometimes if your legs are bigger and longer, sometimes you can pedal harder than other people.
Ms. Allen: Is there any…so pedaling harder. Do you agree with that Sam?
Sam: Um, like a little and not a little.
Ms. Allen: Say some more.
Sam: Because I race my brother sometimes and his legs are longer than mine. And I defeat him some of the times and then sometimes I don't. And it's like it's kind of hard to explain.
Ms. Allen: Well, keep going. You're doing a fine job. You're saying that, for you, that's evidence that the length of your legs doesn't make a difference. Because you know that the length of your legs are different and sometimes you win and sometimes you lose.
Sam: It's more of the strength inside of your legs at the certain time.

In the same way that Ms. Allen may have supported Renee in accessing her prior experience simply by asking the students to consider Leonard's idea, Sam also seemed to reflect on his prior experience as a standard against which to evaluate Leonard's (and Bethany's) assertion. Importantly, he then based his dissenting assertion on experiences he had while racing his brother. Sam initially stated this dissenting response in a doubtful manner by saying that he agreed "a little and not a little." But in response to Ms. Allen's prompting ("Say some more"), he went on to reference his prior experience that when he raced his brother he sometimes defeated him and he sometimes didn't. Then when Sam expressed slight frustration at not being able to explain his idea well, Ms. Allen utilized the second type of discourse move I have noted, an elicitation technique, to help him elaborate and build upon his experience. She first complimented him for the comments he had already made and showed him that she understood him by paraphrasing his words. She positioned him as a scientifically capable thinker by "refining" (Beck et al., 1996) his language and using scientific terminology ("…for you, that's evidence…") to describe his thinking. This appeared to encourage Sam for he was able to elaborate again and pose a more definitive claim ("It's more of the strength inside of your legs at the certain time").

Thus, it appeared that attributes of the curriculum, specifically the hypothetical bike race scenario between Lesley and her friends, provided the content to which Sam and Renee made connections. But, Ms. Allen supported both Renee and Sam in accessing these prior experiences by facilitating a connected discourse between students. She also helped Sam to build upon his prior experiences by using elicitation techniques. These practices are consistent with interdisciplinary recommendations that instruction be implemented in a way that helps students to build new knowledge from their starting conceptions (Donovan & Bransford, 2005; Smith et al., 1997).

Lampert and colleagues (Lampert, Rittenhouse, & Crumbaugh, 1996; Lampert, 2001) have discussed the value of exposing students to multiple and opposing viewpoints through a connected discourse amongst students. This type of activity provides students with multiple opportunities to reflect on their own assertions and to investigate alternative interpretations of mathematical problems. Furthermore, Lampert et al. (1996) also argued for the teacher's critical role in facilitating this type of "disagreeable" discourse. Their research showed that students preferred not to engage in this type of discourse because it was socially not preferable. For example, students reported feeling personally attacked when their peers repeatedly admonished their views even after they had revised their original assertions. Thus, Lampert argued that the teacher is charged with two critical responsibilities. She must both focus students' disagreement in ways that clarify important conceptual differences in the distinct perspectives; and she must also model the social norms that offer students safe mechanisms for expressing their thinking when it is different from their peers (Lampert et al., 1996, p. 760).

In a manner that is consonant with Lampert's recommendations, *Excerpts 8* and *9* showed how Ms. Allen supported students in elaborating upon opposing viewpoints in a way that did not privilege certain students over others. The subtle way that she did this might only be made salient by providing an illustrative contrast. Toward this goal, I also provide an excerpt from Mr. Cannon's first-hand investigation instructional group during the *Prepare to Investigate* phase. In contrast to the instructional setting that Ms. Allen facilitated, Mr. Cannon frequently cut students off or dismissed their dissent if they voiced an opposing, but incorrect, viewpoint. Such an example is shown in *Excerpt 10,* when Mr. Cannon's group was deriving a testable question that related the model back to the original biking event.

Excerpt 10

Mr. Cannon: And how would we state the questions in relation to the race itself?
Ted: How does changing the number of people change the time it takes for the cart to get to the board or to the end of the race?
Mr. Cannon: Say that again louder.
Ted: How does changing the number of people change the time it takes for the cart to get to the end of the race?
Mr. Cannon: Anybody disagree with that? Everybody agree with that? Let's put it that way. Sound like a good question? Yeah. Sandra?
Sandra: No.
Mr. Cannon: That sounds like a pretty good question. Let's write that one down.

Although the transcript excerpt makes it less clear than the video viewing, Sandra's vocal tone when responding "No" made it quite clear that she disagreed with the question posed by Ted. But as demonstrated, Mr. Cannon readily dismissed Sandra's dissent, thus preventing dialogue between student thinkers and suggesting a lack of value for Sandra's ideas. In fact, she was not even given a chance to elaborate upon the reason for her disagreement.

This contrast shows that teachers are in a position to facilitate instructional settings where students are supported to express their opinions, whether those opinions are based on their prior experiences or any other beliefs. In Sandra's case, Mr. Cannon did not support her in reflecting upon or sharing the reason for her dissent. But Ms. Allen collected multiple responses to Leonard's assertion and allowed several students to elaborate, thus facilitating a dialogue amongst thinkers. Parallel to the recommendations suggested by Lampert et al. (1996), Ms. Allen provided a safe intellectual environment where all students could safely reconsider their own and one another's assertions. Specifically, by encouraging students to deliberate over Leonard's idea, Ms. Allen appeared to support Renee and Sam in considering their prior experiences and building upon them.

I note here again that I do not believe that the discourse moves Ms. Allen utilized to support students in building upon their prior experiences were enabled by specific features of the second-hand investigation mode as compared to the first-hand investigation mode. Both instructional modes offered students the opportunity to consider a hypothetical bike race that could have provided the content upon which to make connections with their prior experiences. In both instructional modes, and likely across other forms of instruction also, teachers could support students to access their prior experiences by inviting them to evaluate each other's ideas. The same outcome might be achieved by asking students to evaluate ideas presented in textbooks, whether those texts feature second-hand investigation or not. Furthermore, once students do indeed access those prior experiences, across instructional settings, elicitation techniques such as those used by Ms. Allen would help children to construct new understandings based upon those experiences.

Argumentation Lens

The argumentation analytical lens elicited two sets of findings related to characteristics of the instructional modes and teacher moves as points of mediation for children's learning opportunities. The first set of findings focused on factors that mediated children's engagement with the scientific practice of controlling variables and with conceptual claims that were based on the practice of controlling variables. Particular characteristics of the second-hand investigation instructional mode, including the provision of a common and reliable set of data that was clearly portrayed in the notebook text, offered significant affordances for children's learning opportunities. Ms. Allen also utilized several critical discourse moves that brought these affordances of the notebook text to life.

The second set of findings focused on children's engagement with the scientific practice of multi-variable prediction and with conceptual claims that were based on the practice of multi-variable prediction. Again, particular characteristics of the second-hand investigation instructional mode, including an eloquent portrayal of Lesley's thinking about the opposing mass-motion and force-motion relationships and the provision of a table that saliently demonstrated the possibility of a tie between the bike riders, offered significant affordances for children's learning opportunities. And again, Ms. Allen utilized several critical discourse moves that brought these affordances of the notebook text to life. In the following sections, I first elaborate upon my findings around the practice of controlling variables and follow with my findings around the practice of multi-variable prediction.

The Instructional Mode as a Point of Mediation for Opportunities to Learn about Control of Variables

A challenge of the first-hand investigation instructional mode is that it is highly possible that students will collect unreliable data. Furthermore, others have confirmed the possibility of errant learning as a result of inquiry-based learning (Holliday, 2001; van Lehn, 1990). This possibility seems particularly likely when students have collected unreliable data themselves (Schneider et al., 2005; Hammer, 1997), which they then use to support their conclusions. While this is a realistic challenge associated even with professional scientific inquiry, the classroom context may not allow for the necessary time to engage in repeated data collection aimed at improving reliability.

On the other hand, the second-hand investigation instructional mode was not constrained by this possibility. In conducting her instruction, Ms. Allen could be certain that the notebook text, which had been designed by the GIsML research group, provided her students with reliable data. Thus, there was no risk that the data would support their development of inaccurate conceptual understandings. *Excerpt 11* illustrates this point. It depicts Table 2 from the notebook text, and shows Lesley's data presented in a clear way. The data are also reliable in that they accurately relate mass-motion and force-motion relationships.

Excerpt 11 (from Notebook text, week 1, p. 3)

Table 2: Summary table of the effect of changing the amount of mass and force on the motion of a cart.

Mass (# blocks)	*1*			*2*			*3*		
Force (# washers)	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (seconds)	*1.2*	*1.1*	*1.0*	*1.4*	*1.2*	*1.1*	*1.6*	*1.3*	*1.2*

This affordance of the notebook text may not seem particularly significant unless contrasted with an example of what can occur when students collect unreliable data, as the case was with Ms. Baker's first-hand investigation instructional group. During the *Prepare to Report/Report* phase, Ms. Baker posted a transparency, depicted in Figure 5.2, which showed the data that the students had collected. It appeared that she intended to use these data to help students articulate mass-motion and force-motion claims.

Modeling Ellie in bike race, strongest pedaling

	Mass	1 block			
	Force	3 washers			
	Group	Kiely & Mia	Sam & Dion	Shawn, Mira & Kurt	Ellie & Shelly
Time (seconds)	Trial 1	0.58	**0.97**	**1.57**	
	Trial 2	0.62	0.87	1.73	
	Trial 3	0.80	2.51	1.64	
	Trial 4	0.65		1.21	
	Trial 5	0.65		1.25	

Modeling Kurt in bike race, strongest pedaling

	Mass	2 blocks			
	Force	3 washers			
	Group	Kiely & Mia	Sid & Dion	Shawn, Mira & Kurt	Ellie & Shelly
Time (seconds)	Trial 1		**0.95**	1.42	1.20
	Trial 2		0.81	0.68	1.22
	Trial 3		2.51	**1.38**	0.53
	Trial 4				0.69
	Trial 5				

Figure 5.2. Transparency posted on October 29

However, several minutes into the lesson, Ms. Baker realized that the student data were unreliable. Only two student groups had collected enough data to attend to the mass-motion relationship when force was held constant. Furthermore, these two sets of data supported an inaccurate conceptual understanding – that as the mass on the cart increased, it would take the cart *less* time to travel across the board.

Upon recognizing that these data were unreliable, and presumably also taking into account that there was insufficient time for engaging students in another set of investigations, Ms. Baker took other steps to guide the students to accurate conceptual understandings. She removed the transparency shown in Figure 5.2 and posted a transparency showing Table 2 from the notebook text (see *Excerpt 11*). The table showed Lesley's summarized data, showing only the median value for each set of trials. Ms. Baker provided no explanation to the students about where this table had come from. She then continued her instruction, using this table instead to facilitate student engagement with the mass-motion relationship. This was an unexpected instructional move that was not intended to be part of the study as it was inconsistent with the first-hand investigation instructional mode. Such a teaching move was an example of "improvisation," (Brown & Edelson, 2003) in terms of the extent to which Ms. Baker improvised her own instructional strategies with minimal reliance on the materials meant for use with this instructional mode.

Nevertheless, despite Ms. Baker's provision of reliable data from the notebook text, as well as both conceptual and procedural support for the control of variables strategy, at the very end of the *Prepare to Report/Report* phase, a student poll revealed that two students maintained their belief that as the mass on the cart increased, the speed also increased. This belief was consistent with the unreliable data they had personally collected. *Excerpt 12* shows Ms. Baker's response to this poll.

Excerpt 12

Ms. Baker: How many people think slower? Could you raise your hands again and I'll count. How many people think it makes it go slower? Wait. I'm not seeing everybody's hands. Kurt is one. Shawn is your hand up or not? I can't tell. It's not up. Mira is your hand up or not? It's not up. Dion's hand is up. 1, 2, 3, 4, Kiely how about you? Sid is up. I'm sorry. 1, 2, 3, 4, 5. Kiely, are you agreeing that it's slower or no? And Mia how about you? You're agreeing it's slower. So 7 people. And how many people think faster? Shawn and Mira. Now what a scientist would do. When a scientist sees a pattern like this. A scientist would say - This is telling me it takes longer each time and the cart goes slower. So a scientist would conclude that it goes slower from this data. But we didn't have a chance to do all of that with our own data. And so it's really important. This week we're going to work with materials again. You're going to have a chance to collect your own data again. And hopefully you'll be able to tell from your own data. Because right now we're looking at um not everybody's individual data.

Ms. Baker's response to Shawn and Mira was essentially to tell them they are wrong – or at least that a scientist would disagree with them; but she did not engage Shawn or Mira in elaborating upon their thinking so that she could guide them to an accurate understanding. Instead, her words and affective tone captured on the audio recording revealed her sense of defeat ("So a scientist would conclude that it goes slower from this data….But we didn't have a chance to do all of that with our own data….You're going to have a chance to collect your own data again. And hopefully you'll be able to tell from your own data."). Ms. Baker's words suggested that she was not happy with the outcome. But given the need to move on to the second topic of instruction, Ms. Baker likely had no choice but to leave Shawn and Mira with inaccurate conceptual understandings about the mass-motion relationship.

Several researchers have suggested that it is not unusual for students to maintain their beliefs, even in the face of overwhelming evidence to the contrary (Champagne, Klopfer, & Anderson, 1980; Clement, 1982; Driver, Guesne, & Tiberghien, 1985; Gunstone & Watts, 1985; Gunstone & White, 1981). Lampert (1990) described this tendency as at least partially socially-driven, particularly when students "act as if admitting that there is something wrong with their reasoning is an admission that there is something wrong with *them*" (p. 57). Hammer (1997) also described the tension a teacher experiences when children collect unreliable data and then cling to the claims they have derived from those data. This may indeed have been such a situation with Shawn and Mira, whose personally collected data suggested that the speed of an object would increase as its mass increased. The situation also clearly left Ms. Baker in a less-than-preferred situation. Although she did not explicitly articulate any tension she felt about Shawn's and Mira's post-instruction beliefs, her sense of defeat was palpable in her words and tone.

Another constraint that Ms. Baker faced was that, unlike the second-hand investigation instructional mode, her students were engaged in looking at their own unique sets of data. This made it difficult for her to facilitate a focused whole-group discussion around making evidence-based claims. This was evident, in *Excerpt 13,* when one group of students (Mira, Kurt and Shawn) reported to the class that as they added blocks onto the cart, it went faster.

Excerpt 13

Mira: The more we add blocks on to…
Kurt: …the cart goes faster.
Ms. Baker: Any questions about the claim?
Dion: Did they say blocks? Oh, if you put more blocks on it, how many washers do you have?
Ms. Baker: Shawn can you help them with the question? What does your data say?
S: 0.
Ms. Baker: No, that's not what he asked. You gotta answer his question.
Dion: You guys shoulda' wrote the washers.
Ms. Baker: Can you answer his question?

The excerpt demonstrates Dion's lack of familiarity with his peers' data set, in that he had to inquire how many washers were on the cart. Ms. Baker needed to facilitate discussion between Dion and his peers so that they could understand each other's confusion. In contrast, Ms. Allen had been able to focus all of the students' attention entirely on one set of data. This affordance of the second-hand investigation instructional mode allowed for a more fluid and coherent discussion where time did not need to be spent on sharing multiple sets of data.

Teacher Moves as a Point of Mediation for Opportunities to Learn about Control of Variables

The common set of reliable data provided in the notebook text afforded the opportunity for all students to engage with accurate conceptual understandings. However, Ms. Allen also served as a point of mediation for her students' engagement with the scientific practice of controlling variables and with conceptual claims that were based on the practice of controlling variables. There were specific ways that she brought the affordances of the notebook text, namely its clear and reliable depiction of the data, to life.

Ms. Allen utilized particular learning activities and discourse moves to engage students with the scientific practice of controlling variables and with the related practice of stating scientific claims. At a discourse level, Ms. Allen provided students with graduated prompts to help them locate the relevant data cells in Table 2 of the notebook text that would support the articulation of an accurate mass-motion claim. And at a broader level, she engaged them in this procedure with a conceptual basis. The following analyses demonstrate both of these practices.

Ms. Allen began to engage students in the practice of controlling variables by working with Aaron at the overhead projector. She asked him to use Table 2 from the notebook text to show the class what happens to the speed of the cart as you add mass. *Excerpt 14* shows the transparency and the transcript segment where Ms. Allen guided the class in thinking through, both conceptually and procedurally, why and how one should control for variables.

Excerpt 14

Table 2: Summary table of the effect of changing the amount of mass and force on the motion of a cart.

Mass (# blocks)	*1*			*2*			*3*		
Force (# washers)	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (seconds)	*1.2*	*1.1*	*1.0*	*1.4*	*1.2*	*1.1*	*1.6*	*1.3*	*1.2*

Aaron: The cart goes faster when you add this one and it goes even faster with one more. And it goes even faster than 2 if you add 3. (pointing to mass of 1 blocks with changing force of 1, 2, then 3 washers)

Ms. Allen: Well, come here for just a second and let's check that out. So you're suggesting that we. Now remember. What are we going to have to keep the same to answer this question about what happens as you add mass? Can we be changing both the mass and the force at the same time? Oh no! Absolutely not! So, let's look at. Which one do you want to look at - the mass when you have a force of 1, 2, or 3? You choose. Sam?

Sam: 3.

Ms. Allen: 3. Alright. What happens when you add mass and you have the force of 3? So the first number. What time do you get here?

Aaron: 1.0

Ms. Allen: (circles 1.0 on transparency) And then what happens the next time when you increase the mass by one and you're still using a force of 3, what time do you get? Everybody be thinking. Where did she add a mass of 2? Where does she have 2 blocks? (Aaron points to the overhead.) Alright. And what which is the which shows us where she had a force of 3? (Aaron points) OK. And so what's the time?

Aaron: 1.1

Ms. Allen: OK. (Circles 1.1 on transparency) 1.1 seconds. And now she adds yet another block to have a mass of 3. Ok. And the time was?

Aaron: 1.1,1.2 seconds.

Ms. Allen: OK. (Circles 1.2 on transparency) Everybody. Open your journals quickly and write. Thank you Aaron. Write what do you think she can say just looking at those times? As you add mass and you keep the force the same, what happens to the speed of the cart?

The excerpt shows how Ms. Allen first briefly explained the rationale for looking only at the data cells where force is held constant by saying, "Can we be changing both the mass and the force at the same time? Oh no! Absolutely not!" The class had also discussed the rationale for controlling variables during the *Prepare to Investigate* phase (see *Excerpt 4*). After setting this conceptual basis for the control of variables strategy, Ms. Allen guided the class in procedurally locating the data cells that show the mass-motion relationship with force held constant. Importantly, she then moved directly from engaging students in this practice to engaging them in writing scientific claims in their journals. These two practices are both conceptually and procedurally linked. One must both conceptually and procedurally engage in controlling for force in order to isolate the effect of mass on an object's motion and then articulate the relationship into the form of a claim. Thus, Ms. Allen fluidly moved students from one scientific practice to the next.

Ms. Allen then gave the students approximately 3 minutes to write their claims. During those 3 minutes she circulated the group giving them individual assistance in articulating their thinking. After this, she reconvened the group, explained to the students that they had just written "claims," and asked them to state their claims aloud. Her explanation of what a claim is and how one goes about writing a claim was conceptually rooted. In fact, she did not even tell the students that they were engaging in a procedure called "writing claims" until they had already done so. Instead, she introduced the practice by supporting them in thinking through what their conceptual claims were and then asking them to share their ideas. This is shown in *Excerpt 15.*

Excerpt 15

Ms. Allen:	Alright. Quickly, we're going to sample the claims. These are called claims by the way. They're things that we think are accurate. They're statements that reflect what we think is accurate given the data that Lesley had. Lawrence, you're going to go first, please. What claim did you think Lesley could make about what happens to the speed of the cart when you add mass?
Lawrence:	Do you write it or what?
Ms. Allen:	No just say it out loud to us.

Lawrence: The speed will go faster as you take away mass.
Ms. Allen: Do you all agree? The speed goes faster as you take away the mass. What do you think Leonard?
Leonard: I think that that's right.
Ms. Allen: You agree?
Leonard: Yes.
Ms. Allen: How did you word yours Renee and then Leonard? I had already told Renee she could go.
Renee: It went up by 1 or 2 tenths of a second.
Ms. Allen: OK. So the time of, the time went up by 1 or 2 tenths of a second as what? As Lesley?
Renee: Um. Added mass.
Ms. Allen: OK. Your turn. Leonard and then Tania?
Leonard: I wrote when you add mass, the cart went 1 tenths of a second slower.
Ms. Allen: Do you all agree? Look at all these different ways that you are finding basically saying same thing. To make the same claim but in different words. Thank you Leonard. Tania, you were going to come up next?
Tania: As it gets heavier, and it then the time gets slower.
Ms. Allen: OK. As the cart got heavier, the time got slower. Alright.

The excerpt shows students giving claims in their own words. Ms. Allen had engaged them in procedures that supported this articulation, but these procedures were conceptually driven. All along, student focus was on thinking about what the mass-motion relationship was.

Ms. Baker's approach to engaging her first-hand investigation group in controlling variables and in stating claims differed markedly from Ms. Allen's approach. As already explained, Ms. Baker circled the students' median values for each set of trials and then asked them to transfer those values to a summary table. However, she moved them directly from this practice to writing claims. She gave them no procedural guidance with regard to how one would control for variables using the summary table. She also gave no conceptual rationale for why one would need to control for variables, as Ms. Allen had done. This is shown in *Excerpt 16.*

Excerpt 16

Ms. Baker: And from this table you're going to have to figure out what you can claim about the world. You've now run this cart. You've been changing the blocks. You've been changing the washers. So you've been changing the mass. And you've been changing the force. So what's what does the world work like? The more mass we have, what happens? The more force we have, what happens? You have to see what your data say. And you're going to have to write claims.

As shown, students received negligible support, at both a procedural and conceptual level, in controlling variables and thinking through how it was necessary to do so in order to be able to state a claim.

However, it is indeed possible, even likely, that Ms. Baker would have conducted her instruction differently had she had the luxury of more time. In fact, the data corpus provides evidence that time was a major constraint that challenged Ms. Baker. On October 29, 2003, when Ms. Baker decided to extend the *Prepare to Report/Report* phase into week two, she revised her approach to helping students to make claims. In fact, at this time, she engaged the students in an approach to making claims that was somewhat similar to Ms. Allen's approach. This is shown in *Excerpt 17.*

Excerpt 17

Ms. Baker: OK. In order to compare how changing the mass affects the cart, we have to keep the number of washers the same. So here we have a mass of 1. 1 block and 1 washer. Here we have 2 blocks and 1 washer. And here we have 3 blocks and 1 washer. As we increase the number of blocks, what happens to the time? Does it get. Does it stay the same? Does it get higher or does it get lower? What do you see right there?

As shown, much like Ms. Allen, Ms. Baker now provided a very brief conceptual basis for the control of variable strategy ("We have to keep the number of washers the same.") She then gave brief procedural directions for how one would identify the relevant cells showing the mass-motion relationship with force held constant. She also helped the students to link the practice of controlling variables with the practice of stating a claim in a conceptual manner. While Ms. Baker's guidance was much more brief and less developed than Ms. Allen's, her method was similar.

The way that Ms. Baker revised her teaching approach reveals an additional constraint of the first-hand investigation instructional mode. Having taken the liberty of more instructional time, Ms. Baker altered her approach so that it was more richly conceptually rooted. If she had not taken this liberty and had stayed true to the study design, the first-hand investigation instructional mode would not have allowed her the time to teach in this way. One might also assume that had she had more instructional time available to her, she may have further developed the conceptual basis for student engagement in scientific practices, much like Ms. Allen had done. In other words, it is possible that the time demands of the first-hand investigation mode prevent teachers from implementing best practices, despite their knowledge of and desire to use those practices. Many researchers (Holliday, 2001, 2004; Shulman & Keislar, 1966; Tuovinen & Sweller, 1999) have pointed to the high demand for time when teaching with an inquiry-based approach; and while all of the instructional modes examined in this study did utilize an inquiry approach, there was clearly a higher demand for time in instruction that involved students in conducting first-hand investigations.

These findings do not support the notion that first-hand investigation cannot support children's engagement with the scientific practice of controlling variables or with engagement with conceptual understandings that require a control for variables. However, they do illustrate the challenges associated with doing so. Certainly, the practices Ms. Allen used, including supporting students to identify relevant data cells that integrated a variable control and linking the procedure of controlling variables with its conceptual rationale, could be applied to instructional settings that involve children in first-hand investigations. But the fact that Ms. Allen's instruction was afforded by the provision of a clearly presented, common and reliable dataset eliminated much of the constraints that Ms. Baker faced. To address these challenges and to accommodate the time students need to collect data, teaching via an approach that incorporates first-hand investigation will likely require relatively more time as compared to teaching via an approach that incorporates second-hand investigation.

The Instructional Mode as a Point of Mediation for Opportunities to Learn about Multi-variable Prediction

Given Kuhn's (2007) recommendation that children should be offered more opportunities to practice the multi-variable prediction skill, a critical affordance of the GIsML motion unit of study, across both the first-hand investigation and second-hand investigation instructional modes, was that it could potentially offer children opportunities to develop an understanding of the opposing mass-motion and force-motion effects. Both instructional modes had the potential to involve children in attempting to explain a tie between bike riders of three different masses. In order for a tie to occur, the heaviest rider would have had to apply the greatest force (in order to compensate for his mass disadvantage) while the lightest rider would have had to apply the least force (in order to compensate for her mass advantage). Indeed, this accurate and complete conceptual understanding integrates a recognition of the opposing mass-motion and force-motion effects. Kuhn's (2007) research demonstrated that children struggle to come to understandings based on multi-variable prediction such as this one.

Thus, given the difficulty children experience in gaining proficiency in multi-variable prediction, it is important to note that the second-hand investigation instructional mode offered children additional affordances for engaging with the scientific practice of multi-variable prediction and with conceptual claims that required the use of multi-variable prediction. *Excerpt 18* shows an excerpt from the notebook text where Lesley eloquently conveyed her thinking about the opposing effects of mass and force on an object’s speed.

Excerpt 18 (from notebook text, week 1, p. 3)

These variables have opposite effects. So, when I’m riding my bike with my usual pedaling, and have a heavy backpack on, I will go slower. But, I can go faster if I pedal harder, and maybe I can pedal hard enough to go the same speed as I do without a heavy backpack. I think that has something to do with why we tied in the race.

In addition, as shown in *Excerpt 19*, the notebook text featured Table 3, which made visually salient the fact that a tie between the three riders was possible if they each applied different forces.

Excerpt 19 (from notebook text, week 1, p. 4)

Table 3: Summary table of modeling the effect of a person’s mass and pedaling force on the motion of a bike.

		People’s Weight		
		Light	Medium	heavy
Pedaling Force	Slight	1.2 sec.	1.4 sec.	1.6 sec.
	Moderate	1.1 sec.	1.2 sec.	1.3 sec.
	Strong	1.0 sec.	1.1 sec.	1.2 sec.

As shown, Table 3 made it visually salient that it would be possible for each modeled biker to complete the race in 1.2 seconds if they each applied a different pedaling force. These affordances of the notebook text provided potential resources for students to engage with the practice of multi-variable prediction and with claims that integrated multi-variable prediction.

As I have pointed out in other cases, the significance of the affordances of the notebook text may not be clear unless one considers the contrasting scenario. I have already pointed out that insufficient time appeared to be a significant constraint that Ms. Baker's first-hand investigation instructional group faced. Despite having borrowed 17 additional minutes of instructional time from the time allocated for the second topic of instruction, there had only been enough time for five of her nine students to report on their findings with respect to mass-motion relationships. Furthermore, there were no students who had had an opportunity to report their findings with respect to the force-motion relationship. Thus, not surprisingly, there had been no opportunity for a whole group discussion around the multi-variable prediction skill and the opposing mass-motion and force-motion effects.

In contrast, the second-hand investigation mode offered children the opportunity to reflect upon multi-variable prediction, at least at a superficial level, by simply reading the text. In other words, compared to the first-hand investigation instructional mode, the second-hand investigation instructional mode afforded children several opportunities for engaging with multi-variable prediction. These affordances included, not only a likelihood that they would have more time to focus on data interpretation, but also the eloquent description in the notebook text of Lesley's thinking and the revealing organization of her data, which both saliently portrayed the opposing effects of mass and force on an object's motion.

Teacher Moves as a Point of Mediation for Opportunities to Learn about Multi-variable Prediction

Given the affordances of the notebook text for engaging children in multi-variable prediction, Ms. Allen utilized several discourse moves that served to bring these affordances to life. In this way, Ms. Allen also served as a point of mediation for children's engagement with the scientific practice of multi-variable prediction and with conceptual claims that were based on multiple variables. Ms. Allen mediated children's engagement with scientific practices and conceptual claims by utilizing three types of discourse moves that enabled them to effectively utilize the multi-variable prediction strategy: (1) by giving children the opportunity to paraphrase Lesley's thinking; (2) by facilitating a connected discourse where children were invited to weigh in on each other's assertions; and (3) by redirecting children when their thinking took them in an unproductive direction. I elaborate on each of these types of discourse moves.

The first type of discourse move Ms. Allen used to enable her students' engagement with multi-variable prediction was to give them an opportunity to paraphrase Lesley's thinking. This is shown in *Excerpt 20,* where Bethany read the particularly critical piece of text where Lesley discusses the opposing effects of mass and force on the motion of an object.

Excerpt 20:

Bethany reads following text aloud:
These variables have opposite effects. So, when I'm riding my bike with my usual pedaling, and have a heavy backpack on, I will go slower. But, I can go faster if I pedal harder, and maybe I can pedal hard enough to go the same speed as I do without a heavy backpack. I think that has something to do with why we tied in the race.

Ms. Allen:	So in your own words what what's Lesley saying there? Go ahead.
Bethany:	Jermaine, he was pedaling um um since he was heavy he was pedaling as hard as he could to go fast. Um. So she's saying this is one of the reasons for because Jermaine. Um if that if it makes you go slower and you were traveling you were pushing down really really hard you could go the same as like um Felicia because um she was pushing um slower but she was much lighter. And um Lesley she was kind of in the middle. So um that's why they all tied.

As I have already noted, engagement in reading the notebook text alone at least exposed students to Lesley's thinking the opposing mass-motion and force-motion relationships. However, even though Lesley articulates her thinking very descriptively in the text, Ms. Allen still facilitated an opportunity for Bethany to engage more closely with Lesley's ideas by giving her an opportunity to paraphrase Lesley's words. Given this opportunity, Bethany's paraphrase of Lesley's claim showed that she formulated her own understanding of the mass-motion and force-motion effects. She did not repeat Lesley's words identically. Instead, she applied a concept that Lesley discussed back to the original bike race scenario. Thus, the notebook text served as a springboard from which Bethany developed her own understanding of the practice of multi-variable prediction and of the opposing mass-motion and force-motion effects.

The second discourse move that Ms. Allen utilized to support students' engagement with multi-variable prediction was to facilitate a connected discourse. While studying Table 3 of the notebook text (see *Excerpt 19)*, Renee made the critical observation that the data showed a time of 1.2 seconds for the cart modeling each of the three bikers. Upon hearing Renee's critical observation, Ms. Allen immediately tried to facilitate other students' entry into the conversation. This is shown in *Excerpt 21.*

Excerpt 21

Renee: Well, I notice that um if you go slanted, that it goes um 1.2 tenths of a second all the way down.
Ms. Allen: Does anyone else know what Renee is talking about? Come on up here Leonard and show here what Renee means what you think Renee means.
Leonard: I don't know exactly what she means because I didn't really hear her that much.
Ms. Allen: OK. Maybe Renee you could say it again? Because it's really important that we listen to one another.
Renee: Well, um right slanted down it has 1.2 tenths of a second. So each of them made…
Leonard: Like so light and slight is 1-2. Moderate and medium is 1.2 tenths of a second. And strong is heavy is 1.2 tenths of a second.
Renee: Yeah. Each one. Well each, at least one time they made 1.2.
Ms. Allen: Do you want to circle those times? Leonard is that what you were going to observe?
Leonard: Yeah.

As shown, though Renee made this critical observation, Leonard also engaged closely with Lesley's depiction of the data. Of course, Ms. Allen largely facilitated this engagement by explicitly asking the students to consider each other's thinking, particularly when Renee's observation was so critical.

Ms. Allen's efforts appeared worthwhile, because a few moments later, Leonard articulated a claim that accurately integrated the mass-motion and force-motion relationships. As shown in *Excerpt 22*, Ms. Allen seized this opportunity to connect Leonard's and Renee's ideas to a claim Bethany had made much earlier in the lesson.

Excerpt 22

Leonard: Well, like what Renee said, is that like slight and light would be like Felicia because she's light and slender. So and then she got like for the model she got 1.2 tenths of a second. And like moderate and medium would be like Lesley. She got 1.2 tenths of a second. And strong and heavy would be Jermaine. He got 1.2 tenths of a second. So that might be the explanation why they tied the race.
Ms. Allen: Bethany, is that similar to what you were saying? Not when you were making this observation. But very earlier, much earlier when you were giving your explanation of how the 3 of them tied. If I'm not mistaken, I think you had the same explanation.
Bethany: Yup.
Ms. Allen: Mm hmm!

This type of teacher move demonstrates an alignment with many research-based recommendations. First, it was clear that Ms. Allen supported the development of a connected discourse (Goldenberg, 1992) where students were encouraged to respond to one another's ideas (Beck et al., 1997; Chapin et al., 2003; Lampert, 1990; Lampert et al., 1996). This type of dialogue forced students to communicate the nuances of each other's thinking and thus engaged them in deep thinking about scientific ideas. Also, Ms. Allen skillfully served as a collective memory (Palincsar et al., 2001) for the class. Bethany's original contribution could easily have escaped recognition in the complexity of this conversation. However, Ms. Allen had monitored the ongoing conversation so carefully that she could pull on those threads that would best advance the conversation. This also allowed students to see the connections between what otherwise might have appeared to be disparate understandings. All in all, it was clear that the connected discourse Ms. Allen facilitated supported students to engage in deep thinking about scientific ideas.

One final discourse move that Ms. Allen utilized was to simply discourage a line of thinking that Bethany engaged in. This also occurred after Renee had noticed that the data showed a time of 1.2 seconds for the cart modeling each of the three bikers. In the context of this discussion, Bethany noticed another pattern going from the bottom left cell to the top right cell. *Excerpt 22* shows this discussion.

Excerpt 22

Bethany:	I noticed something else about. If you look at it the other way and it goes sideways, it um goes up by um 2 seconds.
Ms. Allen:	Maybe you need to come up and point. I'm not quite sure I. Oh, you're saying. Oh, I see. Does that? So what would that be examining? What would that be telling us about? When we look at these patterns, we want to try to understand. Hmm. Are these meaningful patterns? Do they tell us something?

In this case, Ms. Allen appeared to notice that Bethany's contribution could take the class in an unproductive direction. It appeared that she initially intended to probe Bethany to elaborate by saying, "Maybe you need to come up and point." Then, once she recognized that there was no potential for productive thinking, Ms. Allen did not hesitate to redirect Bethany. In other words, when necessary, Ms. Allen sometimes responded with direct guidance in issues that seemed to be particularly problematic. This type of discourse move is consonant with Goldenberg's (1992) recommendation that when necessary, teachers should provide direct teaching of skills and concepts. These examples, in conjunction with others I have already provided, demonstrate how Ms. Allen developed a balance between positioning students as "knowers" who can construct their own understandings, while also recognizing that there would be times when they needed direct teacher-provided explanations.

In sum, these analyses show how at least three of Ms. Allen's students arrived together at a co-constructed accurate and complete conceptual understanding of the bike race phenomenon that integrated the opposing mass-motion and force-motion effects. What is more is that the other six students who had not made oral contributions to this part of the dialogue potentially formulated their own accurate and complete conceptual understandings as they listened to their peers. In other words, the comments made by Lesley in the notebook text and by Renee, Leonard, Bethany and Ms. Allen in the class discussion provided opportunities for learning for all the students present.

It should be noted that the notebook text alone or Ms. Allen alone may not have been able to provide students with the fodder for thinking that they needed to consider the opposing mass-motion and force-motion relationships. Ms. Allen's discourse moves served to weave the curricular affordances with student voices in such a way that at least several students were able to walk away with a firm understanding of multi-variable prediction as it related to mass-motion and force-motion relationships. But importantly, this was an affordance of the instructional mode that she was able to harness.

CHAPTER 6: CONCLUSION

Overview

I begin this chapter by reviewing the most critical findings from this dissertation study. I first summarize the general findings that I derived from the guiding framework for the GIsML motion unit of study. I then review findings from the macro-analytical video viewing that responded to the first research question, which asked, "*What are the differential opportunities students have to engage with scientific practices and to acquire accurate conceptual understandings in a first-hand, second-hand or first-hand followed by second-hand investigation?"* Following this, I highlight the main findings elicited from the cross-case analyses with respect to the second research question, which asked, "*What mediates the learning opportunities for engaging with scientific practices and acquiring accurate conceptual understandings across and within conditions?"*

After this review of the study's critical findings, I discuss its implications with regard to the design of educative curricula, teacher education, and educational policy. Finally, I discuss the study's limitations and conclude by suggesting directions for future research.

Differential Opportunities for Engaging with Scientific Practices and Conceptual Claims across Instructional Modes

The initial stages of the macro-analysis revealed some general trends about the conduct of the GIsML inquiry cycle during a two-week implementation. The guiding framework that I developed made it clear that learning was guided by different questions and different purposes for engaging with scientific practices across the different phases of the GIsML inquiry cycle. The most critical difference was that children were expected to be arriving at accurate conceptual understandings by the *Prepare to Report/Report* phase. But during the earlier phases of instruction, accuracy of children's conceptual understandings was not expected. Another general finding was that across instructional modes, during the *Engage* phase, children tended to be more highly engaged with articulating conceptual claims than with scientific practices. This finding paralleled several calls for instruction to initially elicit children's prior conceptions such that continued instruction can build upon those understandings (Donovan & Bransford, 2005; Lampert, 1990; Smith et al., 1997).

The macro-analytical video viewing also responded more directly to the first research question. My findings suggested that instruction featuring second-hand investigation was consistently richer with opportunities for children to engage with scientific practices and conceptual claims than instruction featuring first-hand investigation during the phases of instruction that I analyzed. Of the six rich cases I identified, five featured second-hand investigation; and of the six lean cases, five featured first-hand investigation. However, I did not attend to instruction during the *Investigate* phase, when children in the first-hand investigation instructional mode collected data. Because the research called for following the teacher and not the students, the video footage did not capture children's engagement with scientific practices and conceptual claims during this phase. Thus, it is possible that my research did not reveal critical learning opportunities that were characteristic of the first-hand investigation instructional mode during that particular phase of instruction.

I have also identified several other caveats that should be taken into consideration with regard to these claims regarding the relative richness of instruction featuring first-hand and second-hand investigation. First, although some consistent patterns about particular instructional modes did seem evident, I also recognized that students, teachers and curricular attributes are in constant interaction with each other (Ball & Cohen, 1996; Brown & Edelson, 2003; Cohen & Ball, 1999; Remillard, 1999; 2000) and that these interactions collectively resulted in opportunities for learning. It is thus impossible to say that one of these factors alone was the source of opportunities for learning scientific literacy. I have also recognized that several context-specific characteristics may have affected the results of this study. Students in this study had no prior classroom-based scientific inquiry experience and so they may have particularly struggled to adapt to the first-hand investigation instructional mode. The study was also only conducted over the course of two weeks; and therefore, care must be taken with respect to generalizing from this study.

In addition, I have recognized the role that the particular problem space of the GIsML motion unit of study may have had in affecting the study results. The conceptual terrain featured complex and abstract ideas related to mass, motion and gravity. It is possible that there were challenges associated with first-hand investigation for this type of a problem space in particular. For example, the relative richness of instruction featuring second-hand investigation may have resulted because it concretized abstract content for students in a way that was more accessible than instruction featuring first-hand investigation. The result may very well not have been the same if the instruction had targeted other scientific content. For example, Goldenberg (1992) acknowledged that instructional practices used in instructional conversations are more suitable for so-called "ill-structured" domains where concepts are fuzzier and explicit steps toward successful performance cannot be followed (p. 324). Indeed, in this study, instructional conversations that were largely conceptually-focused were more commonly associated with instruction featuring second-hand investigation than first-hand investigation. However, Goldenberg also recognized that this type of instructional conversation is not necessarily recommended for instruction across all domains. In other domains that are more "well-structured," procedurally-focused instruction may be more supportive of student learning. In other words, the content of instruction should be considered before determining the most appropriate method of instruction. Instruction featuring first-hand investigation may be more supportive of learning in other problem spaces. My point, quite simply, is that it is important to consider alternative explanations before claiming that investigation featuring second-hand investigation is definitively richer than first-hand investigation.

In fact, the time-based analysis I conducted also indicated that over the longer term, the amount of time that students would spend in particular GIsML inquiry phases would shift. During week one, students who experienced first-hand investigations spent the greatest proportion of time in the *Prepare to Investigate* phase; and with the additional demand to allocate time for investigating, they simply had less time, relative to groups who experienced second-hand investigation, to deliberate over the data and articulate related claims in the *Prepare to Report/Report* phase. This may explain why - at least in week one - students experiencing first-hand investigation appeared to generate fewer accurate conceptual claims than students experiencing second-hand investigation and why the leanest case in the *Prepare to Report/Report* phase featured first-hand investigation. But in week two, the proportions of time shifted such that even students who experienced first-hand investigations spent the greatest proportion of time in the *Prepare to Report/Report* phase relative to other phases. This finding suggests that if GIsML instruction were implemented over an even greater duration of time, there would likely continue to be shifts in the way time was spent. Such shifts would likely correspond to shifts in the types of learning opportunities that were presented to students. The claims I have articulated with regard to the relatively richer opportunities for learning associated with the second-hand investigation instructional mode are intended to be specific to the particular context within which this study was conducted.

Factors that Mediated the Differential Opportunities for Engaging with Scientific Practices and Conceptual Claims across Instructional Modes

Following from the macro-analytical video viewing, the cross-case analyses investigated the factors that mediated the differential learning opportunities across conditions. It should be noted, however, that by closely examining the rich cases, two of which featured second-hand investigation, and by closely examining the lean cases, all of which featured first-hand investigation, my analyses tended to reveal challenges associated with instruction featuring first-hand investigation and affordances associated with instruction featuring second-hand investigation. In addition, as I have noted already, I recognize that the learning opportunities that arose in each instructional group were context-specific and thus were born out of an interaction among teachers, students and curricular attributes.

The three analytical lenses, featuring a focus on participant structures, connections to prior experiences, and argumentation, each revealed different affordances of the second-hand investigation instructional mode and the ways that these affordances were brought to life by Ms. Allen's instructional moves. First, my analyses that were guided by a focus on participant structure revealed the potential for the second-hand investigation instructional mode to engage children in the use of a textbook in a participatory manner (Wade & Moje, 2000), such that they were positioned as "knowers" who participated in a scientific inquiry. This was a critical finding, given the tendency for instruction featuring first-hand investigation to be most commonly viewed as the instructional format that would best support learners in "participating" in scientific inquiry. As I have noted, one could argue from a constructivist perspective that learners are more likely to construct deep conceptual understandings when those understandings are based upon data they have collected themselves. The cognitive activity involved in carrying out a scientific investigation is also similar to the practices of professional scientific communities. Thus, children experience first-hand the critical practices of professional scientists. Palincsar and Magnusson (2006) hypothesized that there were additional affordances of the first-hand investigation instructional mode. They argued that direct experiences in scientific investigation afford children the opportunity to try out and test one's thinking and ultimately to concretize scientific relationships about the physical world. In addition, they cited the benefit of collaboration during investigation, which approximates the actual conduct of scientific inquiry in the professional science community.

I do not believe that my findings confirm or refute any of these hypotheses. However, my findings have revealed several participation-based affordances of the second-hand investigation instructional mode and the realistic related challenges associated with implementing instruction featuring first-hand investigation. Features of the text that made Lesley's thinking processes transparent throughout the conduct of a scientific investigation made it possible for children to participate in or to evaluate those same thinking processes. Ms. Allen brought this affordance of the notebook text to life by designing learning activities that approximated the actual conduct of scientific investigation, such as illustrating and interpreting Lesley's investigation. She also utilized the following discourse moves that positioned students as being knowledgeable: by associating ideas with the names of the students who generated them and by giving students opportunities to confirm that she was representing their ideas correctly, by encouraging students to evaluate the conceptual rationale for Lesley's engagement with particular scientific practices, by equating students with professional scientists or mathematicians, and by performing procedures before reading about Lesley's performance of those procedures. Thus, the study's findings suggest that it might be possible for teachers to enact second-hand investigations in a way that approximates some important dimensions of a first-hand investigation. In contrast, the first-hand investigation instructional mode required teachers to provide greater procedural support for conducting an investigation, relative to the second-hand investigation instructional mode. It appeared that students in the lean cases often engaged in procedures without a conceptual basis. In other words, this was a tradeoff of learning through first-hand investigation.

The analyses that were guided by a focus on children's connections to prior experiences revealed the potential for students to make connections to the hypothetical biking scenario posed in the notebook curricular materials. Ms. Allen brought this affordance of the notebook text to life by utilizing two types of discourse moves that enabled children to build upon their prior experiences: by facilitating a connected discourse where children were invited to weigh in on each other's assertions and by using elicitation techniques to help children elaborate and build upon their experiences. Clearly, these same instructional moves could be associated with first-hand investigations as well. In the corpora I analyzed from first-hand investigations, I did not see instances of children making connections to prior experiences.

The analyses that were guided by a focus on argumentation revealed affordances that increased the potential for the notebook text to engage children in the argumentation strategies of *control of variables* and *multi-variable prediction*. A challenge associated with instruction featuring first-hand investigations was that it required teachers to facilitate discussions around multiple sets of student data, some of which were unreliable. In addition, my study confirmed the high demand for time that many researchers (Holliday, 2001, 2004; Shulman & Keislar, 1966; Tuovinen & Sweller, 1999) have already associated with inquiry-based teaching; and while all of the instructional modes examined in this study did utilize an inquiry approach, there was clearly a higher demand for time in instruction that involved students in conducting first-hand investigations. Ms. Baker's instructional group was particularly illustrative in this regard. The high demand for time was so severe that her students did not have adequate time to fully report on their findings. In fact, there was also insufficient time for Ms. Baker to even determine if any of her students had derived conceptual understandings that integrated an understanding of the opposing effects of mass and force on an object's motion.

These issues did not hamper instruction featuring second-hand investigations. Lesley's data provided a common and reliable source of evidence that teachers could use to support students' development of conceptual understandings. Because all of the students were focused on one common set of data, basic location and identification issues were quickly resolved - thereby creating more opportunities to focus on deeper conceptual issues such as articulating evidence-based claims that integrated control of variables. Ms. Allen supported students in reaping the benefits of these affordances by offering them graduated prompts to identify the data that would support the articulation of accurate mass-motion claims, while controlling for force. But importantly, she engaged them in this procedure while also considering the conceptual rationale for control of variables.

The notebook text also provided teachers and students with an eloquent description of Lesley's thinking and a revealing organization of her data, both of which facilitated student engagement with multi-variable prediction as it related to the opposing effects of mass and force on the motion of an object. Ms. Allen supported students in reaping the benefits of these affordances by utilizing the following types of discourse moves: by giving children the opportunity to paraphrase Lesley's thinking, by facilitating a connected discourse where children were invited to weigh in on each other's assertions, and by redirecting children when their thinking took them in an unproductive direction. Ms. Allen's moves collectively showed that she recognized the need for balance in teacher guidance. Most of the time she helped students to construct their own ideas; but when necessary she intervened by providing direct guidance. These instructional moves were consistent with a balanced approach to inquiry-based teaching. Mayer (2004) called for an approach to discovery learning that provides students with “enough freedom to become cognitively active in the process of sense making” and “enough guidance so that their cognitive activity results in the construction of useful knowledge" (p. 16). Similarly, Holliday (2004) called for an approach to science instruction that integrates “opportunities for students to learn on their own through implicit teaching strategies mixed with opportunities to receive explicit teaching” (p. 205). Holliday also recognized that the way that teachers should combine these implicit and explicit approaches is non-linear and depends largely on teachers’ professional judgments. Ms. Allen’s practices provide examples of how teachers and researchers might begin to identify when a situation calls for explicit or implicit teaching strategies. Generally speaking, Ms. Allen helped students to construct knowledge on their own by eliciting their thinking and questioning them in ways that helped them to think productively. However, when they clearly demonstrated significant confusion, Ms. Allen did not hesitate to intervene and provide explicit guidance.

Study Implications

Curricular Design

Given the numerous calls for improved science instruction that would attract more American students to science-related fields (AAU, 2006; AEA, 2005; Augustine, 2007; BRT, 2005; NAM, 2005) and the widespread research-based support for inquiry-based science instruction (NRC, 1996, 2000, 2006), it would seem that this is an approach to science instruction that would be widely supported by educational researchers and schoolteachers alike. However, this has not been the case. Effective inquiry-based science instruction continues to be infrequently enacted in American classrooms, particularly at the elementary level (Glenn Commission, 2000; Weiss et al., 2001).

The findings of this study have illuminated some of the challenges associated with implementing inquiry-based science instruction that features first-hand investigation. I do not assert that instruction featuring first-hand investigation is ineffective or that it cannot be rich with opportunities for learning. Rather, I argue instead that in order for this approach to science instruction to be enacted successfully, it presumes that teachers minimally have large amounts of available instructional time, high content knowledge, and the expertise to make instructional moves that support students in constructing sound conceptual understandings based on data they have collected themselves. Indeed, others have confirmed that inquiry-based science instruction is an extremely demanding form of instruction requiring considerable teacher expertise, not only of scientific content, but also of the pedagogical moves that are likely to engage students in successful inquiry experiences (Cohen, 1989; Shulman, 1987). It also assumes that the conceptual terrain of instruction includes problem spaces that are the right size and offer the proper degree of conceptual challenge, such that students are engaged but not so challenged that they cannot appropriate the results.

Thus, in order to effectively enact inquiry-based instruction featuring first-hand investigations, teachers will need support in acquiring these skills and knowledge bases. The challenges associated with implementing instruction featuring first-hand investigation that were uncovered in this study are very likely the same challenges that prevent actual schoolteachers from implementing inquiry-based science instruction in their classrooms. These challenges include issues such as eliciting and building upon students' prior knowledge, integrating procedural and conceptual understandings, facilitating coherent classroom discussions around multiple sets of student-collected data, some of which may be unreliable, and effectively working within the time constraints of the school day.

If teachers must continue to work within the time constraints of typical classrooms, this study's findings suggest that instruction featuring second-hand investigations of scientific phenomena has potential advantages in engaging children in scientific practices and conceptual understandings. However, many of these advantages can be attributed to the nature of the text that was being used; and furthermore, some of the advantages accrued from the manner in which the teacher mediated the use of those texts. It is entirely conceivable that a teacher could use the notebook text in a didactic manner that would not approximate inquiry and would, in turn, not provide opportunities to acquire concepts and scientific practices.

Thus, whether teachers are to effectively facilitate children's science learning through first-hand, second-hand investigation or both, they will need substantial support in doing so. One means of supporting teachers with developing this knowledge base is through the design and provision of educative curricula (Ball & Cohen, 1996; Davis & Krajcik, 2005) for inquiry-based science instruction. Curriculum designers could make tremendous contributions to the field of education by designing thoughtfully planned curricula, such as the notebook text used in this study, that feature second-hand investigations of scientific phenomena, as well as curricula that feature first-hand investigation, which include support for the addressing the realistic challenges associated with this means of implementing instruction.

The design of such curricular materials should take findings of this study and others into consideration in order to truly facilitate teachers' enactment of inquiry-based science instruction. Many researchers (Ball & Cohen, 1996; Brown & Edelson, 2003; Cohen & Ball, 1999; Remillard, 1999, 2000) have argued that instructional capacity is dynamically determined. Students, teachers, and curricular materials necessarily interact in any instructional setting and thus create differential teaching and learning opportunities. Indeed, numerous studies, such as this one and others (Brown & Edelson, 2003; Chavez, 2003; Puntambekar et al., 2007, Remillard, 1999, 2000; Schneider et al., 2005) have shown that enactments of the same curriculum by different teachers can vary widely. Teachers in my study faced unique situations based on the needs of their students and based on the unique ways that they chose to enact the curriculum. For example, Ms. Baker, likely faced a unique challenge in that her students did not collect reliable data. This forced her to "improvise" (Brown & Edelson, 2003) by supplementing the curricular materials for the first-hand investigation with a data table from the notebook text.

In other words, teaching, is - by nature - dynamic. In this way, my findings contribute to a body of research that has problematized the notion of fidelity of curricular enactment. By its very nature, teaching should be regarded as a "design" activity (Brown and Edelson, 2003) where teachers play an important role as "curriculum developers" (Ben-Peretz, 1990; Remillard, 1999, 2000; 2005). Brown and Edelson (2003) argue that the act of teaching necessarily involves teachers in perceiving and interpreting resources, evaluating the constraints of the classroom setting, balancing tradeoffs, and devising strategies. Thus, this notion of regarding teaching as design should be incorporated into the design of curricular materials. Remillard (2000) criticized typical textbook materials, such as the Harcourt Brace Jovanovich (HBJ) mathematics curricular materials that teachers in her study utilized, for their primary focus on shaping student experiences, implying that it is possible to bypass the teacher in order to shape student thinking:

> …the HBJ guide was designed to provide teachers with a collection of tasks to give to students. It communicated by speaking *through* teachers, by guiding their actions. It did not speak *to* them about these tasks or the ideas underlying them. This choice of language is common among many curriculum guides, which tend to offer steps to follow, problems to give, actual questions to ask, and answers to expect. This approach to guiding teaching emphasizes the outcomes of teaching and not the rationales, assumptions, or agendas supporting them, discouraging teachers from engaging the ideas underlying the writers' decisions and suggestions. (p. 347)

If curricular materials are to be effectively educative and helpful to teachers in implementing challenging forms of instruction, such as either first-hand or second-hand investigation based science instruction, they must embrace more complex notions of teaching.

This study offered additional unique implications for the design of educative curricula based on a logic of inquiry that integrated three analytical lenses: a participant structure lens, a connections to prior experiences lens, and an argumentation lens. A focus on these very issues in the design of educative curricula may be similarly productive. My analytical focus on participant structures uncovered the way that instruction can foster a classroom culture where student thinking is highly valued. The specific findings included particular affordances of the instructional modes and teacher moves that positioned students as having ideas that were worthwhile. This analytical focus was also prominent in the GIsML heuristic (see Appendix A). The heuristic situates all learning activity as occurring within a learning community - thereby suggesting that a critical focus of instruction should be on fostering this community. The design of educative curricula could also attend to this critical aspect of instruction by integrating a guiding analytical question into the design of materials that asks, "How can suggested learning activities and suggested teacher moves position students such that they will be perceived by others and will perceive of themselves as having ideas that are worthwhile?"

My analyses that integrated a connections to prior experiences lens revealed findings about the way that instruction can build upon the intellectual capital that students already have. Indeed, this focus was also prominent in the GIsML heuristic (see Appendix A), as the initial *Engage* phase of instruction is targeted specifically at eliciting children's relevant knowledge and wonderings about the physical world. My analyses additionally uncovered specific discourse moves that demonstrated Ms. Allen's commitment to students' prior knowledge and experiences throughout the GIsML inquiry cycle. This instructional focus on children's prior experience is consistent with Remillard's (1999) construction arena of curriculum development. Remillard explained that in this arena, teachers adapt instruction based on their perceptions of student needs. She argued that adaptation of curriculum materials is particularly likely when student thinking is central to instruction. If instruction is enacted in a way that welcomes unanticipated student ideas such that learners can build upon their prior understandings, a teacher must navigate through these ideas and necessarily make complex and improvisational adaptations to the curriculum. Because of this, Remillard suggests that curriculum materials should be regarded not as blueprints for instruction but as seeds for the instructional path. The design of educative curricula could attend to this critical aspect of instruction by integrating a guiding analytical question into the design of materials, that asks, “How can suggested learning activities and suggested teacher moves elicit and build upon student knowledge and prior experience?”

My analyses that integrated an argumentation lens revealed critical insights for how instruction can support children in making scientific claims. This aspect of instruction was prevalent in many ways in the GIsML heuristic (see Appendix A). First, the *Engage* phase involved children in posing claims about the physical world, and the *Prepare to Report/Report* phase ultimately guided students to support their claims with evidence. The GIsML heuristic also situates the investigation learning activities as occurring within a problem space. In one regard, the problem space of the unit of study I examined was its conceptual or substantive terrain, motion across a horizontal plane. However, in another respect, it could also be argued that the problem space of this particular unit of study was an integration of its syntactic and substantive terrain, which included opportunities for children to develop proficiency in control of variables and multi-variable prediction such that they could ultimately come to conceptual understandings of motion across a horizontal plane. Considering Kuhn’s (1993) conception of science as argument, these aspects of science instruction may be as critical as the conceptual terrain and should perhaps be integrated into what Remillard (1999, 2000) refers to as the mapping arena of curriculum development. It may be productive for educative curricula to not only take into account the way that content is sequenced and organized, but also how the scientific practices that children must engage in to achieve conceptual understandings are organized and sequenced.

In addition, the argumentation lens of my study raises insights for the way that teachers might be supported in Remillard’s (1999, 2000) design arena of curriculum development. While Remillard acknowledges that curricula will necessarily be shaped by teachers' enactments, she also suggests that it may be important for teachers to at least be supported in determining what types of variation upon a curriculum's task representations may or may not be appropriate. Because teachers' enactments of curricular materials are shaped by their unique knowledge, beliefs and dispositions, it is possible to implement a curriculum in a way that does not espouse its epistemological assumptions (Remillard, 2005, p. 221). In the case of the notebook text, for example, it would be possible for a teacher to enact its use in a way that did not engage children in participatory activities that approximated the experience of conducting scientific inquiry. For example, an inappropriate enactment of the notebook text might take children quickly and superficially through the investigative activities and focus their attention instead on the conceptual claims alone. Such an enactment would be considered less than ideal in that it would not reap the benefits of the particular affordances of the notebook text. To prevent this from happening, curricular materials that are educative in design might suggest a range of enactment variations and characterize them as being congruent or incongruent with the epistemological assumptions of the intended instructional approach. With regard to argumentation practices, teachers may benefit from directed guidance as to what they should focus on and how they might integrate those argumentative practices with supporting children's conceptual understandings. The notebook text, for example, suggested many instructional activities and questions that teachers might engage students in considering. It was not expected that teachers would utilize all of these activities and questions. Thus, educative curricula might be helpful by explaining why particular activities and guiding questions are especially critical to engage students with in light of a curriculum's epistemological assumptions.

I also offer recommendations for educative curricular materials at a finer level of detail. My work has shown several discourse moves to be particularly constructive with regard to positioning students as being knowledgeable, making and building upon students' prior experiences, and supporting student understanding of the argumentation strategies of control of variables and multi-variable prediction. Educative curricular materials could present these discourse moves to practitioners in a format that would be very accessible and thus increase their potential to be useful to practitioners across different situations. This could, for example, include charts where particular discourse moves were named and defined. In addition, curriculum writers could include the rationale for such moves and explain why there were likely to be effective. It would also be useful to exemplify the discourse moves using transcript segments from hypothetical classroom scenarios. Ideally, such a chart might depict multiple situations that demonstrated the way that teachers could carve varied instructional paths based on a range of student responses to a particular teacher discourse move. For example, it is indeed possible that a teacher might use a discourse move exemplified by Ms. Allen in this study, such as attempting to facilitate a connected discourse amongst students, and find the students completely unresponsive. For situations such as these, teachers would benefit from multiple depictions of classroom discourse – such that the variations showed how teachers might react in situations where students were initially completely responsive, somewhat responsive or not at all responsive. In a case where students were initially unresponsive, transcript segments could show how teachers might use follow-up discourse moves where they rephrased the question or backed up and clarified meaning.

In addition to the insights that my study has provided for the design of educative curricula, other researchers have suggested that they should acknowledge that teachers engage in varied readings of curricular resources depending on their knowledge, beliefs and dispositions (Remillard, 2000). With this in mind, they must offer teachers more than tasks to enact. To begin with, tasks, as depicted in curricular materials, are only representations of activities (Brown & Edelson, 2003). They do not become actual activities until they are taken up by teachers and students and brought to life. Remillard (2000) suggests several ways that curricular materials can more richly speak to teachers. For example, instead of merely depicting tasks, curricular materials should discuss the underlying goals of suggested tasks. They might also recommend ways that a task might be made more or less complex while addressing the same intended goals but differential student needs. In order to support teachers in envisioning how these tasks may look during enactment, images of student and teacher discourse could accompany teacher guides. Furthermore, such dialogues could include commentary written from teacher or student perspectives about the challenges they face and how they go about addressing these challenges.

Teacher Education

As I have noted, my study has revealed a number of teacher practices that can be regarded as “high-leverage” discourse practices that appear to help children engage in scientific literacy. These findings are relevant for science teachers and teacher educators in the field of science education. Teacher education programs for science teachers ought to provide support for teachers to develop an understanding of such practices, which include the following: 1. Giving students opportunities to confirm the way that their ideas are represented; 2. Encouraging students to evaluate the conceptual rationale for engagement with particular scientific practices; 3. Positioning students as equals with professional scientists or mathematicians; 4. Facilitating connected discourse where children are supported to consider and respond to each other's or a textbook's assertions; 5. Using elicitation techniques to help children elaborate and construct upon prior experiences; 6. Offering graduated prompts to help children interpret data; 7. Redirecting children when their thinking takes them in unproductive directions; 8. Associating ideas with the names of the students who generated them. These types of discourse moves are not applicable to only one instructional mode, but carry promise for any mode of science instruction whose purpose is to engage students in scientific inquiry in a way that positions student thinking at the forefront of instruction.

The suggestions I have made for the presentation of these discourse moves in educative curricular materials also apply to the way that teacher educators could present these moves to future teachers. Future science educators would benefit from considering the rationale for particular discourse moves and the way that they could be implemented in varied situations. In addition, in the teacher education classroom context, there would be a potential for students to grapple with these moves in a more complex way. They might, for example, engage in analyzing video-based or written cases of actual elementary classrooms where teachers and children were engaged in inquiry-based science instruction that illustrated particular teacher discourse moves. Rich discussion could ensue from analysis of such cases and the way that these moves were enacted by teachers and responded to by students. Following from these types of learning activities, future teachers could enact focal discourse moves themselves in their classroom practicum and then analyze their own practice.

The implications of this study are also relevant to the literacy education community who aim to support teacher education students in meaningful ways in the content areas. This community has recognized that language permeates all disciplines (Gee, 2004) and that science involves its own literate practices (Lemke, 2004). Thus, it has a critical role in supporting students to develop subject-specific literacies. In the discipline of science, literacy educators can support teacher education students by preparing them to address children's syntactic and substantive knowledge development. As this study has shown, this development is supported by providing students with rich opportunities for learning though the provision of rich curricular materials, that may or may not involve students in reading and learning from second hand investigations, but that must be supported with meaningful teacher discourse practices and engagement in learning activities that bring the affordances of any curriculum to life.

Educational Policy

Finally, the results of this study also have implications for the depth and breadth of science instruction as it is enforced by local and state policies. It is clear that, in order for inquiry-based approaches to science instruction to be effective, teachers and students need longer stretches of time for instruction that enables a deeper focus on scientific topics. Sherin, Edelson & Brown (2004) explained that in a task-structured curriculum, where students develop scientific knowledge in order to serve a specific overarching goal such as solving a problem or building a device, "…some issues will be covered in great depth (measured against our traditional conceptions of a discipline). In other places, students will learn just enough to ‘get by’” (p. 225). Thus, this type of a curricular design - and others that are also more inquiry-oriented - may require sacrificing breadth of instruction in order to accommodate the depth of understanding that inquiry-based approaches can facilitate. Of course, it will be difficult to make such a transition when teachers face administrative and collegial pressure to produce students who will score high on local and state assessments that require a breadth of knowledge across a wide corpus of scientific topics (Holliday, 2001).

Thus, without significant policy changes that parallel a focus on depth over breadth, it may be wise for schools and teachers to balance science instruction between some implementation of inquiry-based approaches and some implementation of more explicit approaches that include more traditional models of instruction (Holliday, 2001; Shulman & Keislar, 1966). As I have noted already, there have been several calls for this type of balanced approach to science instruction (Holliday, 2004; Mayer, 2004). Holliday (2004) also bemoaned the fact that there is a tendency for professional documents to suggest that “good science teachers emphasize laissez-faire, minimal interventionist instruction, which automatically results in increased students’ inquiry-based abilities and further develops their inquiry habits of mind” (p. 205). He admitted that some documents call for guided inquiry approaches, but they rarely provide concrete examples of how such an approach would be implemented. The results of this study suggest that professional documents for teachers need to provide teachers with more concrete guidance for implementing balanced and guided approaches to inquiry-based science instruction.

Limitations of the Study

While there were several limitations with regard to the design of the study, these aspects of the study have already been described and taken into consideration when reporting its results and implications. First of all, it could be argued that the small number of children per instructional group (n = 7, 8 or 9) challenges the external validity of the study. The typical fourth grade classroom includes 25-30 students; and, thus, the findings from this study may not apply to a more typical classroom. However, this study's purpose was to conduct a fine-grained analysis of interactions amongst teachers, students and instructional modes in order to inform future instruction. A focus on interactions with a smaller number of children helped to achieve this goal.

It is also important to note that the students in this study had no prior experience with scientific inquiry. Their lack of experience may certainly have caused them to struggle more with instruction featuring first-hand investigation, as it was more activity-based than instruction featuring second-hand investigation. Instruction featuring second-hand investigation in this study was also far from traditional, in that the notebook text was unlike traditional textbooks (Hapgood et al., 2004). However, it may have felt more familiar to students to be learning about science from a text than from first-hand investigation. This lack of familiarity with first-hand investigation may have affected the results of the study. Thus, the findings may be less applicable to students who have considerable experience with scientific inquiry and first-hand investigations.

One could also argue that the short length of the study's implementation (two weeks) challenges its external validity. But as I have mentioned, while at first glance this may appear to be a very short duration, science instruction of this depth was rarely implemented at this specific school site nor in general across American classrooms (Weiss et al., 2001; Weiss et al., 2003; Weiss et al., 2004). Thus, relatively speaking, the amount and intensity of science instruction implemented during this study was significant.

I have also pointed out that this research called for following the teacher instead of students during the *Investigate* phase of first-hand investigations. Because of this, the data corpus did not capture children's verbalizations during small group work; and thus my analyses could not attend to the learning opportunities that children engaged with during the *Investigate* phase of first-hand investigations. My hope was that children's engagement with scientific practices and conceptual claims would be revealed during the whole group discussions that occurred during other phases of the GIsML inquiry cycle; but to the extent that this did not happen, my analyses may not have fully captured children's understandings.

In addition, as I have repeatedly noted, the GIsML motion unit of study that was implemented in this study addressed particularly complex and abstract conceptual terrain. Thus the findings reported here may be more pertinent to instruction addressing similarly complex and abstract conceptual terrain. It is indeed possible that the findings I report would not transfer to other contexts that involve instruction in more concrete and tangible problem spaces.

Another limitation of the study may be that the teachers, Ms. Baker, Ms. Allen and Mr. Cannon, had considerable expertise in related content knowledge. They also had co-constructed the specific GIsML curricula used in this study. Thus, the findings from this study would not generalize to instruction conducted by a more typical teacher, who presumably might have less content knowledge than the teachers in the study and who might not have the curricular familiarity that they had. But again, I considered these features of the study to be affordances. Focusing on the enactment of instruction by teachers such as those in this study informs instruction for the more typical teacher. I have also pointed out that it might be argued that my results suggested the superiority of second-hand investigation due to what may have been greater expertise on the part of Ms. Allen, relative to Mr. Cannon and Ms. Baker. One could argue, for example, that if Ms. Allen had taught a first-hand investigation instructional group, the first-hand instructional mode may have been found to be the richest in opportunities for learning. While it is not possible to completely disconfirm this argument, I have also provided counterevidence showing that her interplay instructional group, featuring second-hand instruction in week two, was identified as the leanest case for the week two *Prepare to Report/Report* phase. This would suggest that Ms. Allen was not necessarily more expert than Mr. Cannon and Ms. Baker.

A final limitation of this study is again one that could be considered one of its affordances. This study examined the enactment of instruction. Thus, there were numerous differences across instructional groups that arose because of real-life classroom factors, such as management problems, high-needs students, and scheduling concerns. Real teachers face these types of issues every day, and so they necessarily affect their instruction. The instruction in this study was no different. It was affected by the day to day issues of classroom life as well as by more complex research-related issues, often resulting in teachers straying from exact lesson plans that had been designed for the study. The most extreme examples of this occurred in Ms. Baker's first-hand instructional group, as described in Chapter 5. Ms. Baker made the decisions to extend the time allocated for the first topic of instruction (motion across a horizontal plane) and to use data not collected by the students themselves to support them in developing accurate conceptual understandings. These decisions were presumably ethically-driven. Ms. Baker likely felt that it was more critical to give students the opportunity to derive accurate understandings than to maintain the procedures set forth by the study design. This is indeed a limitation of the study, because enacted procedures did stray from intended procedures; however, I would argue that the teachers rightfully took logistical and ethical matters into consideration when making accommodations.

Directions for Future Research

There are many areas of future research that are called for by this study. First, studies of second-hand investigation and interplay instructional modes for inquiry-based science instruction should be conducted over a longer time span to gain a better understanding of the differential affordances between the two approaches. In this discussion, I have largely commented on the differential challenges and affordances associated with instruction featuring first-hand or second-hand investigations. I have not specifically commented on the relative challenges and affordances of the interplay instructional mode. Because the case studies were based on instruction that occurred in week one only, my analyses did not capture the unique affordances and challenges associated with the interplay mode. The distinctive characteristics of this instructional mode would likely only become clear through a close study of longer-term implementation. Hypothetically, the interplay mode could offer children all the affordances of the second-hand investigation in hand with the affordances of the first-hand mode, which include the actual experience of carrying out an investigation and the associated opportunity to construct knowledge based on data students collect themselves. Clearly, continued research is necessary to test this hypothesis.

In addition, continued research examining the three instructional modes featured in this study should be conducted with larger groups of children that approximate the size of typical classrooms. It would also be enormously beneficial to study the implementation of these approaches to science instruction by actual schoolteachers who have been informed by the findings of studies such as this one.

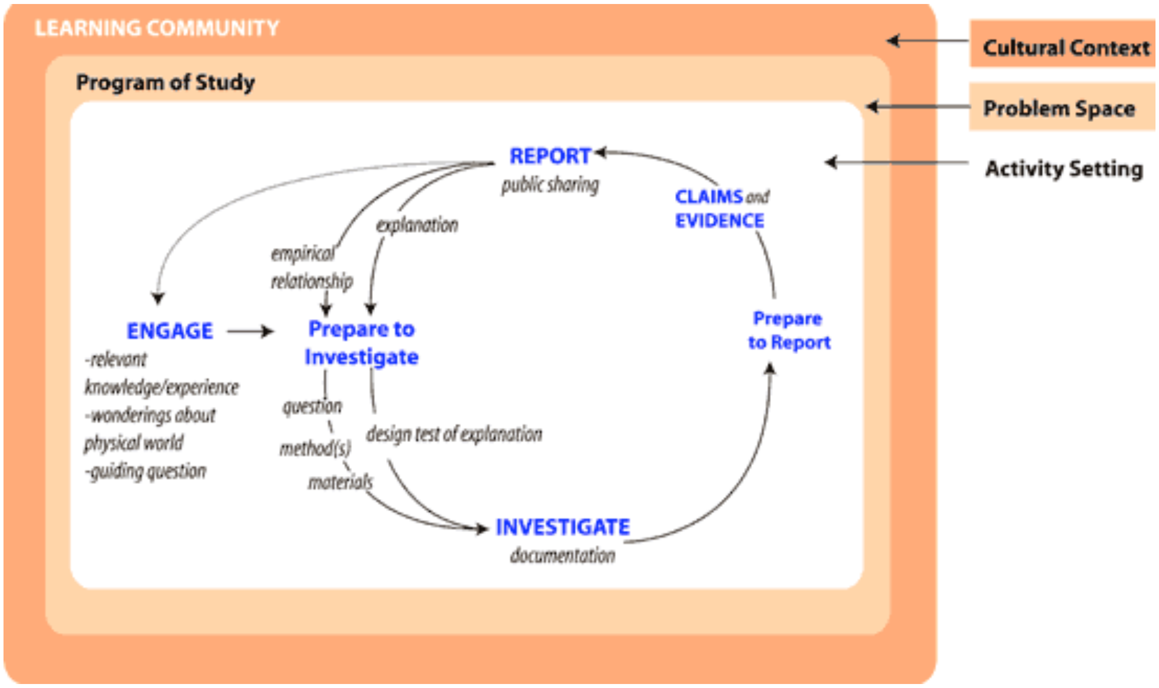
During the conduct of this study, it became clear to me that that there is a wider range of scientific practices that students engaged in than those I had identified as my focus. These additional practices could be objects of continued study. For example, some of these practices included the following: critiquing an investigation design, supporting a claim with evidence, setting up an investigation, and designing aspects of an investigation. This study focused on children's engagement with conceptual understandings and with nine specific scientific practices. However, continued study of children's engagement with a broader ranger of scientific practices could potentially enrich the findings of this study.

The conduct of this study also illuminated another rich area of future inquiry. While this study generally studied children's engagement with scientific practices and conceptual claims as separate activities, it became clear that there may be relationships between these two endeavors. Future study could examine the patterns between these two types of activities. For example, continued study could determine whether engagement with particular types of practices is more likely to lead to engagement with particular types of conceptual understandings.

Finally, as I have already mentioned, this study did not consider children's learning outcomes, other than the conceptual understandings that they verbalized during instruction. As described in Chapter 3, learning outcome data are indeed available; but the data are complex and do not reveal clear patterns with regard to the effectiveness of the different modes of instruction across the two weeks of instruction and across both content and reasoning knowledge. Continued study could examine the associations between the opportunities for learning uncovered in this study and the learning outcome data, both at an individual level and at the level of instructional groups or instructional modes. Such an analysis might allow for more definitive conclusions to be made about the effectiveness of the instructional modes examined in this study.

Thus, the findings of this study open up the possibility for several potentially rich areas of future study. This study has tangibly demonstrated the complexity of classroom instruction that features inquiry-based science instruction. While indeed, this is a form of instruction that has the potential to support children's rich understandings of scientific content and scientific practice, it is also a form of instruction that is extremely challenging to implement. With this in mind, continued study of the enactment of inquiry-based science instruction can improve understandings of the challenges inherent to inquiry-based science instruction and thereby also develop a finer understanding of ways to address these challenges.

APPENDIX A: GIsML HEURISTIC DIAGRAM



(Note: From http://www.umich.edu/~gisml/heuristic.html)

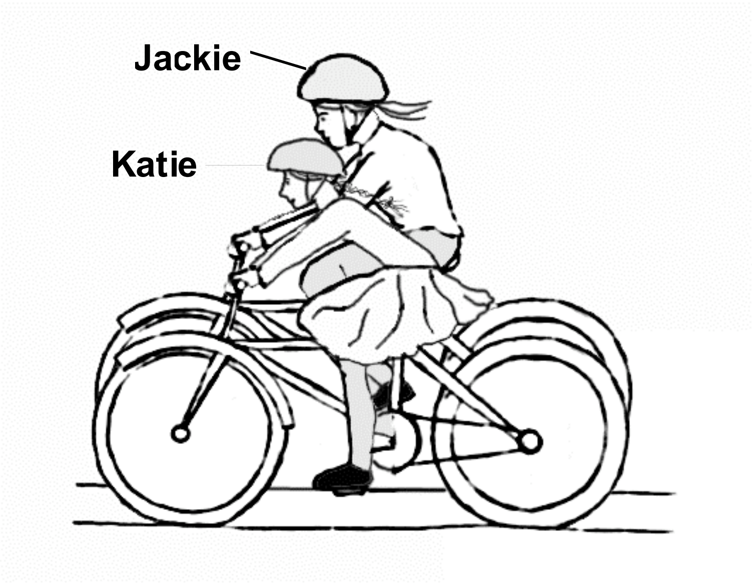
APPENDIX B: KNOWLEDGE ASSESSMENT PART 1

Name________________________
Teacher________________________

Date__________________

1. Rachel rowed across a lake in 47 seconds. If she rowed again with the same force but used a heavier boat, how would her time compare? *Circle the best answer.*
   a) It would be slower because the boat is heavier.
   b) It would be faster because the boat is heavier.
   c) It would be the same because the distance across the lake did not change.
   d) It would be the same because she rowed with the same force.

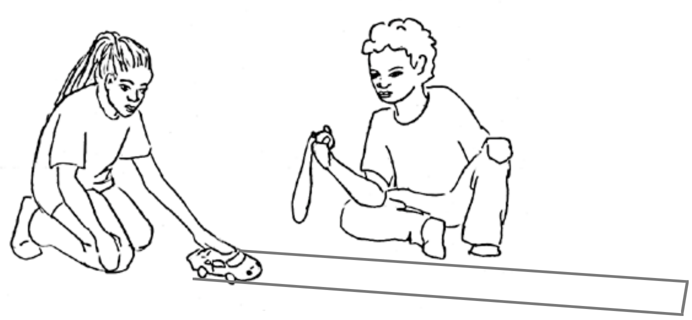
Jackie and her little sister Katie rode on bikes that were the same. Jackie is much heavier than her sister Katie.



2. If they race their bikes along a flat sidewalk, could they tie? *Circle the best answer.*

   a) No, Jackie will win because she can pedal with more force and go faster.
   b) No, Katie will win because Jackie is heavier and will go slower.
   c) Yes, because Jackie can pedal with to make up for being heavier than her sister.
   d) Yes, because Jackie and Katie are riding bikes that are the same.

Jada gave her toy car a push on a track to see how fast it would go. Jamal timed how long the car took to get to the end of the track. The table shows their data.



Trials	**Time** (seconds)
1	The car did not get to the end of the track
2	20
3	10
4	15

3. In Trial 1, how much time did it take the car to reach the end of the track?
Circle the best answer.

a) 10 seconds
b) 15 seconds
c) 20 seconds
d) The car did not get to the end of the track.

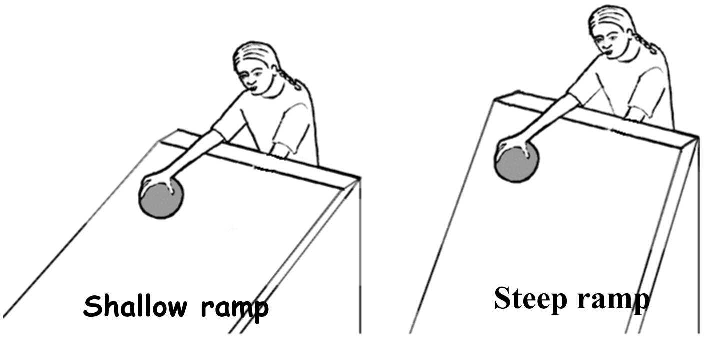
4. In which trial did the car travel the fastest? *Circle the best answer.*

a) Trial 1
b) Trial 2
c) Trial 3
d) Trial 4

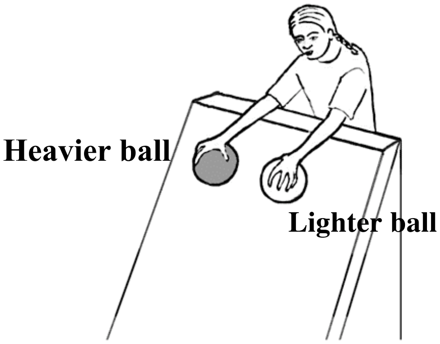
5. Jada thought having more trials would help them make a scientific claim. How would doing more trials help Jada and Jamal make a scientific claim?
Circle the best answer.

a) Having more data helps make a claim scientific.
b) Having practice measuring helps make a claim scientific.
c) Having more times close to the same helps make a claim scientific.
d) Having more times that are fast helps make a claim scientific.

Tanya holds a ball at the top of two ramps of the same length.
The **shallow** ramp is low. The **steep** ramp is higher.



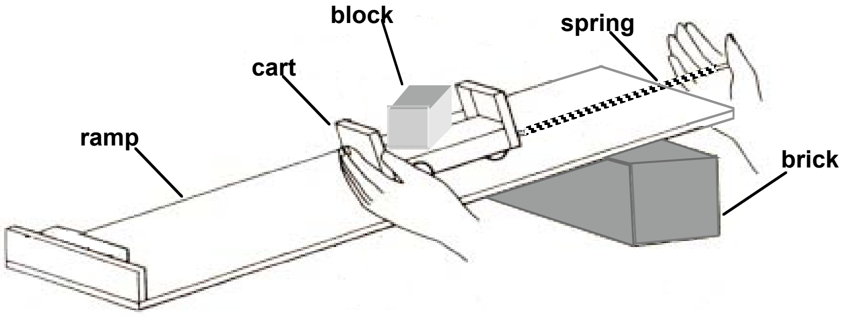
6. How does the ball on the *shallow ramp* compare to the force on the ball on the *steep ramp*? *Circle the best answer.*
   a) The force on the ball was greater on the shallow ramp.
   b) The force on the ball was greater on the steep ramp.
   c) The force on the ball was the same on each ramp.
   d) There was no force on the ball on either ramp.



7. Tanya gets a heavier ball of the same size and measures the force on each ball at the top of the steep ramp. On the steep ramp, how does the force on the heavier ball compare to the force on the lighter ball? *Circle the best answer.*
   a) There is more force on the heavier ball.
   b) There is more force on the lighter ball.
   c) There is the same amount of force on each ball.
   d) There is no force on either ball.

8. On the steep ramp, which ball will get to the end *sooner*? *Circle the best answer.*
   a) The heavier ball.
   b) The lighter ball.
   c) Both balls will take the same amount of time.

Jack attached a 10 cm spring to the back of a cart.



9. When he put the cart with one block on a ramp, the spring stretched to 11 cm. What does the stretch of the spring measure? *Circle the best answer.*
   a) The force on the cart.
   b) The force on the ramp.
   c) The force of gravity.
   d) The force of the spring.

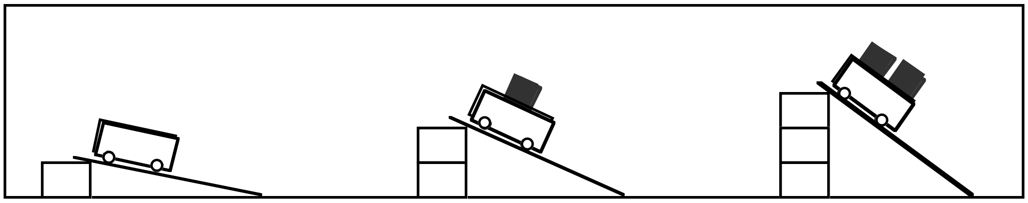
Jack put blocks on the cart and measured the length of the spring. Each time Jack added another block to the cart, the stretch of the spring became longer.

10. What does the stretch of the spring tell use about the force of gravity? *Circle the best answer.*
    a) The force of gravity is always the same.
    b) The force of gravity is greater on heavier objects.
    c) The force of gravity is greater on lighter objects.
    d) The spring cannot tell us about the force of gravity.

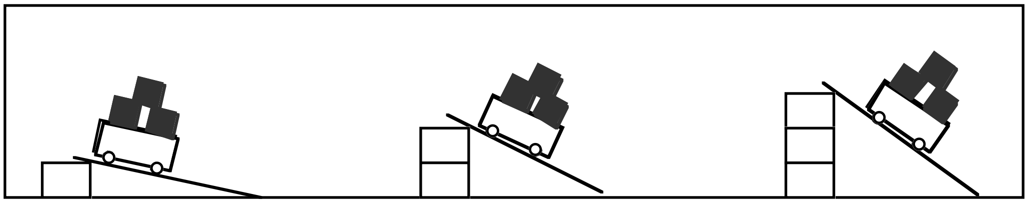
Abdul had some carts and some blocks. The blocks were all the same mass.
He wanted to test the idea that ***A heavier cart goes down a ramp faster.***

11. Which set-up should he use to test this idea? *Circle the best answer.*

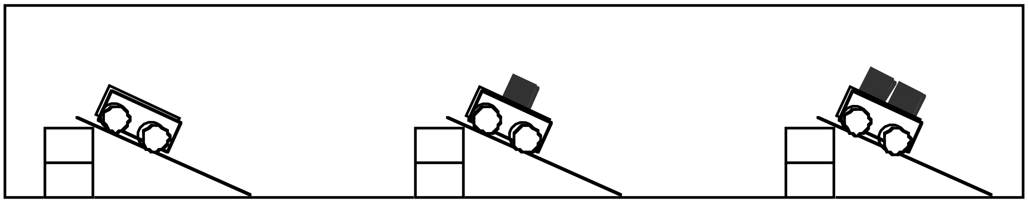
a)



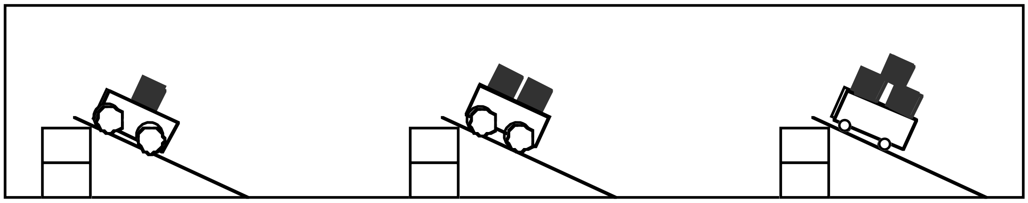
b)



c)



d)



APPENDIX C: KNOWLEDGE ASSESSMENT PART 2

Name____________________________ Teacher ________________________

Date___________________

Pedro and Samantha went roller blading. Two friends held them in place at the top of a hill and then let go. Pedro and Samantha rolled to the bottom of the hill.

1 Samantha and Pedro rolled down the hill for multiple trials. What does it mean to do multiple trials? *Circle the best answer.*

a) They rolled down the hill several times.

b) They each rolled down the hill from different starting points.

c) They rolled down the hill at different speeds.

d) They rolled down several different hills.

2. Pedro and Samantha got to the bottom of the hill at the same time. What variables would have caused this to happen? *Circle the best answer.*

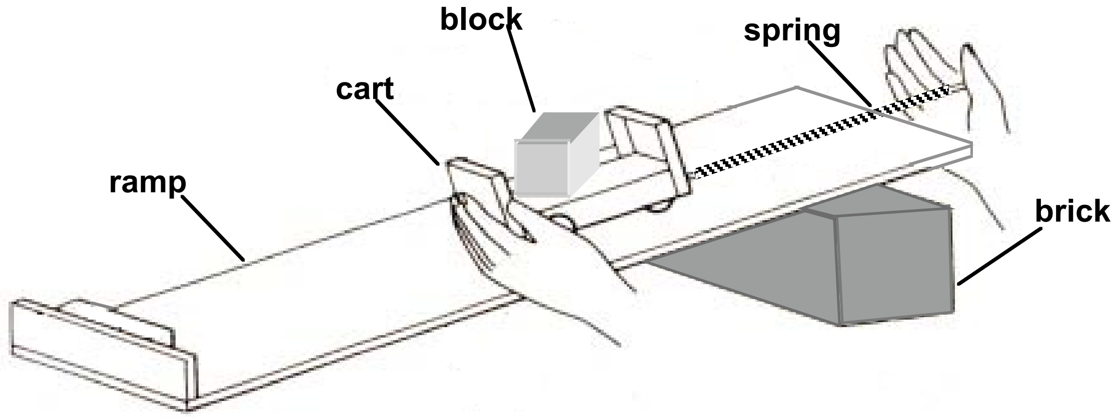
a) The people's weight and the steepness of the hill.

b) The people's weight and the force of gravity on the people.

c) The force of gravity on the people and the steepness of the hill.

d) The steepness of the hill and the height of the hill.

Samantha and Pedro used the materials shown to model what happened in their roller blade races.



3. What does the **RAMP** in the model stand for in the roller blade race?
   Circle the best answer.
   a) gravity b) height c) hill d) people e) roller blades

4. What does the **CART** in the model stand for in the roller blade race?
   Circle the best answer.
   a) gravity b) height c) hill d) people e) roller blades

5. What does the **BLOCK** in the model stand for in the roller blade race?
   Circle the best answer.
   a) gravity b) height c) hill d) people e) roller blades

6. What does the **SPRING** in the model stand for in the roller blade race?
   Circle the best answer.
   a) gravity b) height c) hill d) people e) roller blades

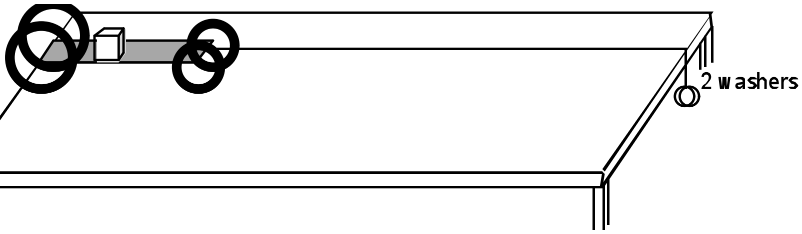
Pedro and Samantha placed blocks on a cart to find out how the heaviness of a cart affects the time it takes it to go down a ramp. The table shows the data they collected.

		Mass on Cart (number of blocks)		
		1	**2**	**3**
Time (seconds)	Trial 1	2.43	2.40	2.47
	Trial 2	2.44	2.43	2.45
	Trial 3	2.47	2.44	2.43

7. When the cart had 1 block on it, how long did it take to get to the end of the ramp in Trial 2? *Circle the best answer.*
   a) 2.40 seconds
   b) 2.43 seconds
   c) 2.44 seconds
   d) 2.45 seconds

8. What claim could you make from the results in the table? *Circle the best answer.*
   a) The cart took longer to get down the ramp each time.
   b) The cart took over 2 seconds to go down the ramp in each trial.
   c) The cart took different amounts of time to go down the ramp in each trial.
   d) The cart's mass did not affect the time it took to go down the ramp.

Ling and Peter were studying motion with the materials in the drawing. They used stop watches to measure the time a cart took to reach the end of the table.



Ling and Peter recorded the following set of data.

	Time (seconds)
Trial 1	1.81
Trial 2	1.74
Trial 3	1.62
Trial 4	1.69
Trial 5	1.81

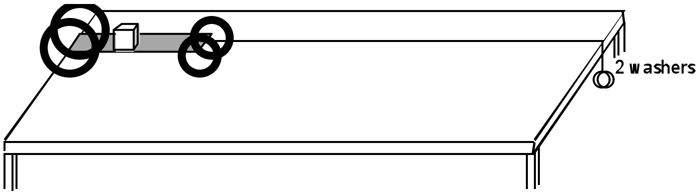
9. What number would a scientist use to describe what happened in the trials? *Circle the best answer.*

   a) 1.6 seconds
   b) 1.7 seconds
   c) 1.8 seconds
   d) 1.81 seconds

10. How does a scientist decide what number to use to describe what happened in the trials? *Circle the best answer.*

    a) Use the fastest time the cart took to travel.
    b) Use the typical time the cart took to travel.
    c) Use the time the cart took most often.
    d) Use the first time that was measured.

Here are Peter and Ling's final results for the cart.



		MASS (number of blocks)		
		1	**2**	**3**
FORCE (number of washers)	**1**	1.7 sec.	1.9 sec.	2.0 sec.
	2	1.6 sec.	1.7 sec.	1.8 sec.
	3	1.4 sec.	1.5 sec.	1.6 sec.

11. Using Ling and Peter's results, which set-up would create a tie with a cart carrying 1 block and pulled by 2 washers? *Circle the best answer.*

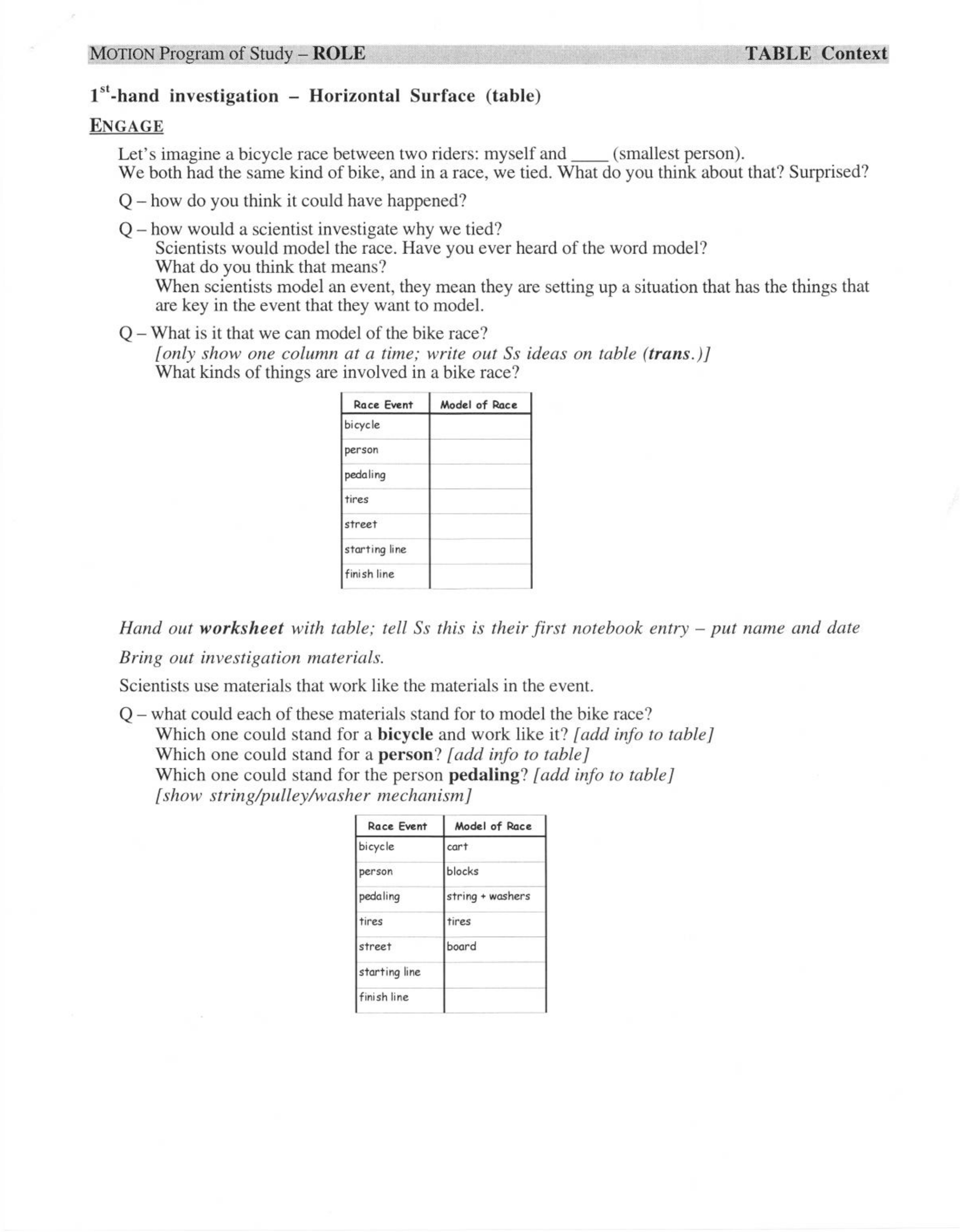
a) a cart with 1 block pulled by 1 washer.

b) a cart with 2 blocks pulled by 2 washers.

c) a cart with 2 blocks pulled by 3 washers.

d) a cart with 3 blocks pulled by 3 washers.

APPENDIX D: LESSON PLANS FOR WEEK 1 FIRST-HAND INVESTIGATION



MOTION Program of Study – **ROLE** **TABLE Context**

1st-hand investigation – Horizontal Surface (table)

ENGAGE

Let's imagine a bicycle race between two riders: myself and ____ (smallest person).
We both had the same kind of bike, and in a race, we tied. What do you think about that? Surprised?

Q – how do you think it could have happened?

Q – how would a scientist investigate why we tied?
Scientists would model the race. Have you ever heard of the word model?
What do you think that means?
When scientists model an event, they mean they are setting up a situation that has the things that are key in the event that they want to model.

Q – What is it that we can model of the bike race?
*[only show one column at a time; write out Ss ideas on table (**trans.**)]*
What kinds of things are involved in a bike race?

Race Event	Model of Race
bicycle	
person	
pedaling	
tires	
street	
starting line	
finish line	

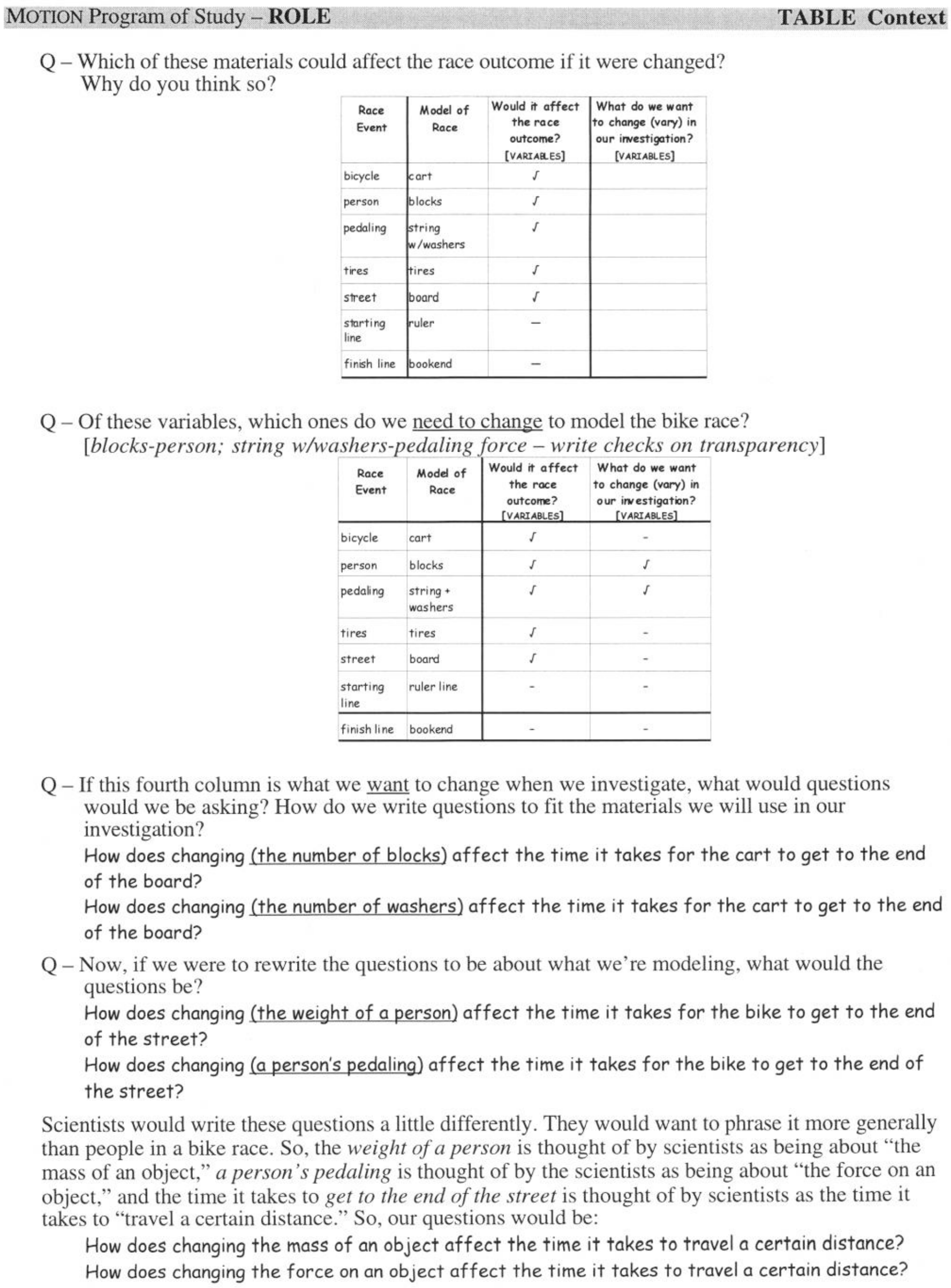
*Hand out **worksheet** with table; tell Ss this is their first notebook entry – put name and date*

Bring out investigation materials.

Scientists use materials that work like the materials in the event.

Q – what could each of these materials stand for to model the bike race?
Which one could stand for a **bicycle** and work like it? *[add info to table]*
Which one could stand for a **person**? *[add info to table]*
Which one could stand for the person **pedaling**? *[add info to table]*
[show string/pulley/washer mechanism]

Race Event	Model of Race
bicycle	cart
person	blocks
pedaling	string + washers
tires	tires
street	board
starting line	
finish line	



Q – Which of these materials could affect the race outcome if it were changed? Why do you think so?

Race Event	Model of Race	Would it affect the race outcome? [VARIABLES]	What do we want to change (vary) in our investigation? [VARIABLES]
bicycle	cart	✓	
person	blocks	✓	
pedaling	string w/washers	✓	
tires	tires	✓	
street	board	✓	
starting line	ruler	–	
finish line	bookend	–	

Q – Of these variables, which ones do we need to change to model the bike race? [*blocks-person; string w/washers-pedaling force – write checks on transparency*]

Race Event	Model of Race	Would it affect the race outcome? [VARIABLES]	What do we want to change (vary) in our investigation? [VARIABLES]
bicycle	cart	✓	-
person	blocks	✓	✓
pedaling	string + washers	✓	✓
tires	tires	✓	-
street	board	✓	-
starting line	ruler line	-	-
finish line	bookend	-	-

Q – If this fourth column is what we want to change when we investigate, what would questions would we be asking? How do we write questions to fit the materials we will use in our investigation?

How does changing (the number of blocks) affect the time it takes for the cart to get to the end of the board?

How does changing (the number of washers) affect the time it takes for the cart to get to the end of the board?

Q – Now, if we were to rewrite the questions to be about what we're modeling, what would the questions be?

How does changing (the weight of a person) affect the time it takes for the bike to get to the end of the street?

How does changing (a person's pedaling) affect the time it takes for the bike to get to the end of the street?

Scientists would write these questions a little differently. They would want to phrase it more generally than people in a bike race. So, the *weight of a person* is thought of by scientists as being about "the mass of an object," *a person's pedaling* is thought of by the scientists as being about "the force on an object," and the time it takes to *get to the end of the street* is thought of by scientists as the time it takes to "travel a certain distance." So, our questions would be:

How does changing the mass of an object affect the time it takes to travel a certain distance?

How does changing the force on an object affect the time it takes to travel a certain distance?

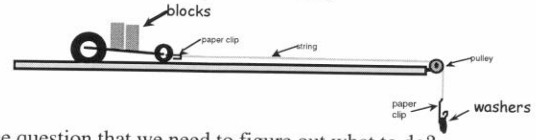
PREPARE TO INVESTIGATE

Now we need to figure out what we're going to do in our investigation. So, let's take each part of the question and see what we think it means we need to do.

Q – what do we to investigate the first part in each question?

- changing the MASS of an object . . .
  - model small person and T with blocks [*show physically w/carts and blocks*]
  - introduce hypothetical person, have Ss model with blocks
- changing the FORCE on an object. . .
  - model forces that could have been exerted by each person [*show w/string and washers*]

[*put up* ***transparency*** *with model, hand out* ***worksheet*** *with model*;
have Ss identify what the parts of the model correspond to in the bike race,
then have Ss write out questions for investigation on worksheet, specifically identifying
what represents mass and what represents force]



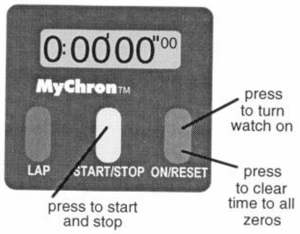
Q – what else is in the question that we need to figure out what to do?

- the time it takes to travel

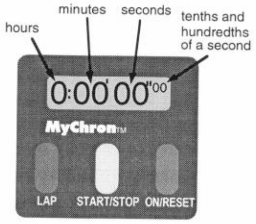
So, how do you think we are going to time?
I have stopwatches for us to use in our investigation. Let me show you them and how to use them, and then we'll practice using them.

Here's what the stopwatch looks like (*show actual stopwatch*).

This is a picture of the stopwatch you'll be using [*show* ***transparency***].
This button is what you press to start and stop the watch.
This button is what you press to get it back to zero for the next time – it <u>resets</u> the time.



Now let's go over how to read the time on the stopwatch.
[*show* ***transparency*** *and go through what each place in the number records*].



This picture shows a stopwatch that timed how long a man held his breath underwater. How long did the person hold his breath? [*show* ***transparency***]

This time is 8 minutes and 6 seconds.

[world record for holding breath under water: by Martin Stepanek - March, 2001]

The way to write this time is: 8:06 seconds. *(write on trans.)*

Here's a picture of the stopwatch after a person was timed running 100 meters. How long did it take the person to run that distance? [*show* ***transparency***]

The way we would say this time is: 10 and 47 hundredths of a second.

[Women's world record: by Florence Griffith Joyner (Flo Jo) - July, 1988]

The way to write this time is: 10.49 seconds *(write on trans.)*

This picture shows a stopwatch that timed how long it took a baseball thrown by a big league pitcher to get from him to the batter. How long did it take the ball to get to the batter? [*show* ***transparency***]

This time is 41 hundredths of a second.

50 hundredths of a second is half a second.

[Fastest recorded pitch in baseball: 100.9 mi/hr by Nolan Ryan - July, 1974]

The way to write this time is: 0.41 seconds. *(write on trans.)*

Pass out stopwatches.
Now, let's practice using the stopwatch. I will say start and stop, and we'll check the times we got.
- to turn the watch on, what do you do?
- to start timing, what do you do? To stop timing, what do you do?

Okay, let's try timing. [give Ss several times to use stopwatch.]

Now let's time something moving. What if we time each other walking toe-to-toe? And hopping?

Q – how should we set this up, if we were going to go a certain distance like in the bike race?
[*prompt Ss to establish starting and finish lines; prompt for strategies to determine when to start and stop the watch*]

- have Ss time one child for each type of movement
- have Ss share the times they got, Ss compare their accuracy with one another
- have Ss time one other child and show table to use to record data [*use **transparency***]

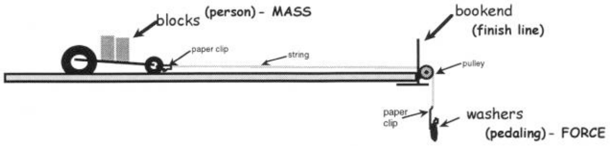
Person	Time Walking Toe-to-Toe (seconds)	Time Hopping (seconds)
Trevor	5.24	3.11

Hand out table for Ss to use to record their data; Ss work in pairs timing one another
Ss record data on transparency for comparison,
T provides feedback as needed to make sure Ss are using stopwatches correctly.

……

Now, back to preparing to investigate with the cart.
Q - If we're going to time the cart, what will we need to do to know when to start and stop the watch?
[introduce ruler as a tool to help establish a starting line]
[introduce bookend as a tool to create a finish line]

Once Ss have established need for starting and finish line, show **transparency** with model, and hand out **worksheet** with model;
have Ss identify what the parts of the model correspond to in the bike race,
then have Ss write out questions for investigation on worksheet, specifically identifying
what represents MASS and what represents FORCE]



When scientists investigate motion of an object like this, they would time the cart more than one time with the same mass and force. When they do the investigation the same way more than once, each time is called a trial.
Q – Why do you think scientists do that?

I'm going to suggest that we do about five trials each time.

Finally, before you start, we need to talk about how to organize all the data that you will collect. Scientists typically use tables to keep track of their observations, just like we did before. So, we need to figure out what our table should look like for the cart investigation.

We might start with naming each person in the bike race that we are modeling.
[*show **transparency**, just one row at a time*]

- How many blocks would we use for the lightest person?
- How many washers would we use for pedaling with the least force? most? a medium amount?

[Fill out for lightest person, but tell Ss they will fill out the table for the rest.]

	Person 1			Person 2			Person 3		
# blocks	1	1	1						
# washers	1	2	3						

Assign groups to collect particular data: each group has the goal of collecting data modeling two of the three people, but if they have time to collect data for all three, that's fine.
[*show full table on **transparency**, and hand out table worksheet.*]

	# blocks									
	# washers									
TIME (seconds)	Trial 1									
	Trial 2									
	Trial 3									
	Trial 4									
	Trial 5									

Tell Ss that they will be sharing their data will the class. They will be making claims, and identifying evidence for those claims, which you will tell them about after they finish collecting their data.

INVESTIGATE

Ss work in pairs.

Monitor for appropriate use of materials, accurate use of stopwatch, accuracy of recording in table.

Note sources of error within and across groups.

Note Ss' progress in collecting data; i.e. extent to which they collected the desired amount of data.

Note the similarity and differences in times recorded.

PREPARE TO REPORT

Now that we've collected data, we need to determine how to answer our questions. To do that, we need to find out whether there are patterns in the data. Since we have trials where we collected data five times but didn't change our investigative set-up, we need to have a way to summarize the information for a set of trials. That is, for each set of trials, we need a way to come up with a single number, so that we have many fewer numbers to look at to look for a pattern.

So, let's all look at our data modeling the first person, the lightest person. And let's start with the column where the person is pedaling with the least force.
Point to that column of data on your data sheet so that I can check that we're all looking at ?

Here's a table of data collected using materials like ours. [*show transparency*]
Q - In terms of a person in the bike race, what does the shaded column represent?
How does the weight of this person compare to the others? How does their pedaling force for these data compare to other times?

		S's name		
	# blocks	1	1	1
	# washers	1	2	3
TIME (seconds)	Trial 1	2.14	1.90	1.62
	Trial 2	2.04	1.92	1.67
	Trial 3	1.98	1.85	1.59
	Trial 4	2.02	1.89	1.60
	Trial 5	2.07	1.88	1.62

To summarize our data for this situation, we're going to use a procedure used by a famous researcher named Dr. Tukey. He wanted a simple way to analyze data, or tell how a group of numbers compared, when there was a lot of data.

First, when there were sets of data, like we have trials, he wanted a simple way to find a single number to represent a set of numbers.

He began by crossing out the smallest part of each number in the set.

		S's name		
	# blocks	1	1	1
	# washers	1	2	3
TIME (seconds)	Trial 1	2.1~~4~~	1.90	1.62
	Trial 2	2.0~~4~~	1.92	1.67
	Trial 3	1.9~~8~~	1.85	1.59
	Trial 4	2.0~~2~~	1.89	1.60
	Trial 5	2.0~~7~~	1.88	1.62

Then, he put the revised numbers in order, from the smallest to the largest.

He selected the number that was in the middle of the other numbers as his representative number because there were just as many numbers larger than that value as there were smaller than that value.

1.9
2.0
2.0
2.0
2.1

In this case, 2.0 seconds is the summary value for this set of trials [*write number below column*].

Try the next two columns of data in your groups, and raise your hand when you are ready to share the summary value that you got.
[Have Ss come up to transparency and write their values as they finish. Have class compare results; resolve any differences in calculations.]

Now that we have the summary information we can put this in a new table.

Mass (# blocks)	1		
Force (# washers)	1	2	3
Time (seconds)	2.0	1.8	1.6

You need to use this same procedure for your data, and then you need to figure out whether you can make any claims.

Let me show you what it means to make a claim.
Here are data from students running 100 meters. They had to run that distance 3 different ways, on three different days.
The first day, a 10 meter section of track was marked off between two lines, and they had to run that section 10 times, turning around each time they got to a line.
The second day, a 25m section of track was marked off between two lines. Now, they had to run that second 4 times, turning around each time they got to a line.
On the third day, a 50m section of the track was marked off, and now they only had to turn around once to run the full distance.

Table 1. Time to run 100 meters

	Time to Run 100m (seconds)		
Length of Track	10 m	25m	50m
# of turns	9	3	1
Tasha	25.5	21.9	19.2
Jimmy	21.9	15.7	13.6
Becki	23.1	17.1	15.5
Regina	22.2	15.1	12.8
Darryl	23.0	16.9	15.4
Antonio	24.8	20.8	16.7

What difference does the track length make in the time it takes to run 100 m?

With that question, what we want to know is: what happens to the time it takes to run the distance, as they have more turns?

Q – Is the time about the same or is it different?

Q – If it's different, does it increase as the number of turns increases or does it decrease as the number of turns decreases?

So, to write a claim, we take the question, and turn it into a statement:

[*begin writing examples, and have Ss generate the information that's underlined; leave transparency up to refer to as an example as they are writing their claims*]

As the track length gets longer/shorter the less/more time it takes to run 100 meters. **OR**

The longer/shorter the track length, the shorter/longer the amount of time it takes to run 100 meters.

Look back at the questions we were trying to answer, and turn those into statements about what you can claim from your data, just like we did here.

[Work individually with small groups, checking understanding of how to construct a claim; and prompt self-evaluation when they have statements by asking how well they think their classmates will understand what they mean to say.]

You will write your claims with markers on a piece of poster paper.

In addition to your claim, you will need to show your evidence. That means showing the data you have that supports your claim.

For the claims with running 100m, we would simply rewrite the table so that it is large enough for everyone to see. That's probably what you'll do in your case.

Encourage students if they can and are comfortable doing so, to write their claims in terms of the bike race that was modeled by the investigation.

[*Note that the table organization used is best for featuring claims relative to force. Thus, for students who also make claims relative to mass, suggest that they reorganize their data to better show their classmates the pattern they saw, and scaffold that as needed.*]

REPORT – PT. I – SMALL GROUPS

Tell students that they will be presenting their claims and evidence, one group at a time, at the front of the room. The students listening to the presentation will have the role of making sure that they understand the claim that is being made, and that they understand the evidence that is presented in support of the claim. Indicate that it will be important for the Ss listening, to examine whether or not they think the evidence is accurate, and whether or not they think it does support the claim.

Ss, one group at a time, share claims and evidence.

As needed, prompt Ss listening to make sure they are understanding the presentation, and to ask questions as needed if they are not.

For each group, ask the Ss listening to say what question they think the group's claim answered, and then have the group confirm or deny their intent to answer the question stated by the listeners.

When the second group reports (and for each subsequent group), have the listeners state whether the claim(s) they are making are the same or different from the other group(s).

- If the same, have Ss identify which other poster(s) contain the same claim.
  Then, ask whether they think the evidence for the other group(s) is the same or different.
  – If different, ask Ss whether they think that makes stronger or weaker evidence for the claim.
  [*if needed tell Ss it's weaker if data are contradictory, otherwise the claim is strengthened*]

REPORT – PT. II – WHOLE CLASS

Discuss which claims are class claims; i.e., there is consensus in accepting them as valid.

Remember that we had an even more work with class to revise class claims to describe the relationships in terms of **mass** and **force** and **time of travel**.

Now, we want to be able to figure out what happened in the bike race.
To do that, it will be helpful to reorganize our data in a different kind of table.

Each of our questions identifies a variable we investigated. What are those variables?

In the tables we've been working with, both variables are shown in columns. But we can make a table where one variable is shown in the rows, and the other variable in the columns.

Let's keep mass in the columns because that represents each person.
How many different values did we have for that variable? *[3]*
We need to have a column for each value of the variable. So, how many columns do we need? [*3*]

Now, let's put the force in the rows.
How many different values did we have for that variable? *[3]*
Again, we need to have a row for each value of the variable. So, how many rows do we need? [*3*]

So, our table looks like this.

		MASS (# of blocks)		
		1	**2**	**3**
FORCE (# of washers)	**1**			
	2			
	3			

Now we take the numbers from our summary table, and determine where to put them in this new table. Using my summary table from before [*show partial table that was used for Tukey procedure*], my first value, which is for a mass of 1 block with a force of 1 washer, would go here.
My second value, which is for a mass of 1 block with a force of 2 washers, would go here.
And my third value, which is for a mass of 1 block with a force of 3 washers, would go here.

		MASS (# of blocks)		
		1	**2**	**3**
FORCE (# of washers)	**1**	2.0 sec.		
	2	1.8 sec.		
	3	1.6 sec.		

Let's take a moment and have everyone put your summary numbers into this new table.

Now, let's see if we can use the data table in this form to see if we can explain the outcome of the bike race.
Q – If the people tied, how would their times compare?
Find the times in your table that are the same.
Q – Could any of the times in your table that are the same, represent different people?
Q – How would you know if they could represent different people? [*mass has to be different*]

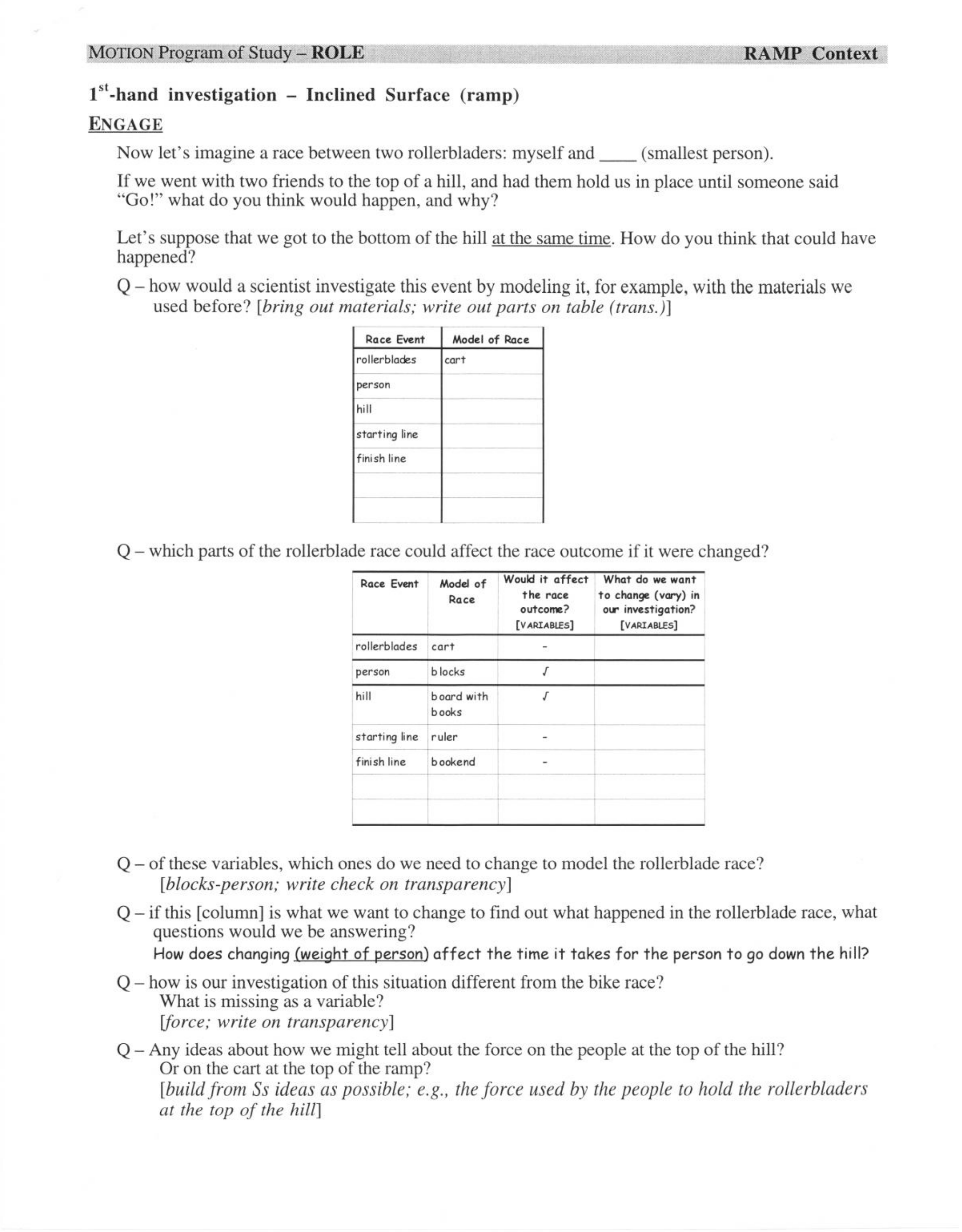
Here's a complete table that includes the data I showed you earlier.

		MASS (# of blocks)		
		1	**2**	**3**
FORCE (# of washers)	**1**	2.0 sec.	2.4 sec.	2.8 sec.
	2	1.8 sec.	2.0 sec.	2.3 sec.
	3	1.6 sec.	1.8 sec.	2.0 sec.

In this table, there are three values that are exactly the same, and they could represent three different people.

Q – If these data represented the people in the bike race, how would we explain that they tied?
[*lightest person pedaled with the least force, heaviest person with the most force, i.e., those who were heavier, pedaled with enough force to make them go faster, to make up for their extra weight slowing them down, compared to the lightest person*]

APPENDIX E: LESSON PLANS FOR WEEK 2 FIRST-HAND INVESTIGATION



MOTION Program of Study – ROLE **RAMP Context**

1^{st}-hand investigation – Inclined Surface (ramp)

ENGAGE

Now let's imagine a race between two rollerbladers: myself and ____ (smallest person).

If we went with two friends to the top of a hill, and had them hold us in place until someone said "Go!" what do you think would happen, and why?

Let's suppose that we got to the bottom of the hill at the same time. How do you think that could have happened?

Q – how would a scientist investigate this event by modeling it, for example, with the materials we used before? [*bring out materials; write out parts on table (trans.)*]

Race Event	Model of Race
rollerblades	cart
person	
hill	
starting line	
finish line	

Q – which parts of the rollerblade race could affect the race outcome if it were changed?

Race Event	Model of Race	Would it affect the race outcome? [VARIABLES]	What do we want to change (vary) in our investigation? [VARIABLES]
rollerblades	cart	-	
person	blocks	✓	
hill	board with books	✓	
starting line	ruler	-	
finish line	bookend	-	

Q – of these variables, which ones do we need to change to model the rollerblade race? [*blocks-person; write check on transparency*]

Q – if this [column] is what we want to change to find out what happened in the rollerblade race, what questions would we be answering?

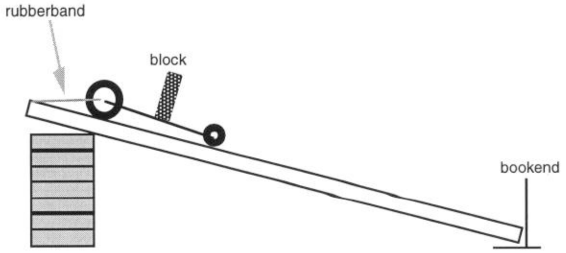
How does changing (weight of person) affect the time it takes for the person to go down the hill?

Q – how is our investigation of this situation different from the bike race?
What is missing as a variable?
[*force; write on transparency*]

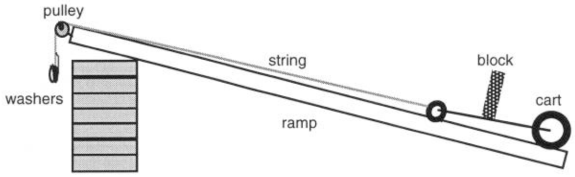
Q – Any ideas about how we might tell about the force on the people at the top of the hill?
Or on the cart at the top of the ramp?
[*build from Ss ideas as possible; e.g., the force used by the people to hold the rollerbladers at the top of the hill*]

I have two different strategies you can use to tell about the amount of force on the cart

- show strategy of using spring to see how much force is on cart at top of ramp



- show strategy of seeing how much force it takes to pull cart up ramp



Q – how would we state a question for what we are doing <u>when we use the spring</u>?

How does changing <u>(the number of blocks on a cart)</u> affect how much a spring stretches that is holding it at the top of a ramp?

Q – how would we state this question in terms of what we are modeling?

How does changing <u>(the weight of a person)</u> affect the force of gravity on it at the top of a hill?

Q – how would we state a question for what we are doing when we <u>pull the c art up the ramp</u>?

How does changing <u>(the weight of the cart)</u> affect how many washers it takes to pull it up a ramp?

Writing this question in terms of what we are modeling would be the same as what we just wrote.

[*How does changing <u>(the weight of a person)</u> affect the force of gravity on it at the top of a hill?*]

So, we can use either of these procedures to tell about the force on the cart.

PREPARE TO INVESTIGATE - FORCE

Choose one of the procedures to use, and collect data. If you have time, you can collect data with both procedures.

You're going to write your data up here so that we can see all the information that the group determined. We will see how your results compared to one another, and we will use all of the results to see what the answer to our question is.

I'd like you to record your data up here (poster paper on board) as you collect it.

INVESTIGATE - FORCE

Ss work in pairs.

Monitor for appropriate use of materials; sources of error within and across groups.

Note Ss' progress in collecting data; i.e. extent to which they collected data with one or both procedures.

Note the similarity and differences in "forces" recorded – expect differences due to differences in weights of the wooden blocks.

Direct Ss to put data on board as they have it ready.

	Spring Stretch (centimeters)				Number of Washers			
Number of Blocks	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Grou 4
1								
2								
3								

REPORT - FORCE

Q – So, what claim can we make about how:

- changing the number of blocks on a cart affects how much a spring stretches that is holding it at the top of a ramp?
- changing the number of blocks on a cart affects how many washers it takes to pull it up a ramp?

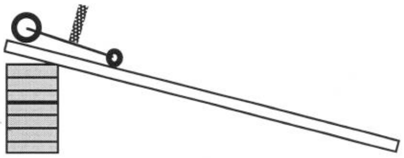
Q – Considering how we wrote the question for what we were modeling, what claim can we make about how changing the weight of a person affects the force of gravity on it at the top of a hill?

PREPARE TO INVESTIGATE - MASS

Q – How do we write these questions to fit the materials we will use in our investigation?

How does changing (the number of blocks) affect the time it takes for the cart to get to the bottom of the ramp?

Now we need to figure out what to do with these materials in order to find out what might have happened with each person in the rollerblade race, and let's add a third hypothetical person again whose weight is between the other two.
- check Ss' ability to model people with blocks (show physically w/carts and blocks)



APPENDIX F: LESSON PLANS FOR WEEK 1 SECOND-HAND INVESTIGATION

Intro to Notebook Text genre:

Today we are going to begin reading part of the notebook of a scientist. A scientist's notebook is one of the most important tools she or he has.

- Why would a scientist keep a notebook?
  (Elicit and record on poster paper the children's thinking)
- What would we expect to find in the notebook of a scientist?
  (Elicit and record on poster paper the children's thinking).

Intro to Writing along with Reading the Notebook Text:

In addition to reading the notebook of a scientist, we are going to keep our own scientific notebooks.

Have you ever written in a journal or had journal time at school? What have you used journals for?
(e,g,To write about a book or an experience, to share with others one's likes and dislikes)

As we read and discuss the scientist's notebook, we are going to use notebooks to record our own thinking. This will enable us to compare our ideas with the ideas of the scientist.

Teaching with the Notebook Text

Each page of the notebook is handed out separately, and as needed. Students keep their own notebook along with their reading.

The prompts to the teacher on the right side of the guide indicate questions and tasks for students to maximize learning from the notebook text. There are more questions on each page than need be asked, however.

Prompts written within a box on the right-hand side are to focus student writing, either on the text itself or in their notebooks.

When Page 1 of Lesley's notebook is handed out, begin by asking the children what they notice about her notebook. Add their comments to the list of "what they would expect to find in the notebook of a scientist."

Scientist: Lesley Park Date: 8/18/03 Page: 1

I was biking with my friends when Felicia challenged us to a race to the park. Jermaine, who is very large and muscular, shouted that he was going to win because his strong legs would make the bike go fast once he got it going. Felicia, who is tall and slender, replied that she was going to win because she was light and her long legs would make her pedaling strong. I thought I might win because I would not weigh down the bike like Jermaine, and I could push the bike harder than Felicia because I can pedal faster with my shorter legs. To my surprise, we all got to the park at the same time! How could that be?

I decided to model this event in order to investigate what happened. I needed an object that moves like a bike, and a force to make the object move, like pedaling makes a bike move. Then, I needed a way to represent our different weights, or that we each are a different amount of mass on the bike. Figure 1 shows what I used for my investigation.

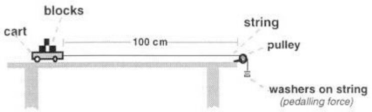


Figure 1. Modeling a heavy person on a bike.

I used materials so that I had three different weights on the cart, and three different amounts of force. I used a stopwatch to time how long it took for the cart to get to the end of the table. I collected data as though I were observing one biker at a time. When I let the cart go, it was stopped by the pulley, so I stopped timing when I heard the cart hit the pulley. I ran a number of trials with each amount of force and mass. If the times were about the same, then I knew I had a good measurement of the time of travel of the cart. Table 1 shows the full set of data I collected.

What does Lesley describe in this first paragraph of her notebook?
What was each biker's thinking about why he or she would win the race?
Were **you** surprised that all three bikers got to the park at the same time? Why or why not?
What are the possible explanations we can think of for why the three bikers got to the park entrance at the same time?

> Suggest that we illustrate the bike race event in our notebooks.
> Ss and T share and compare their illustrations of the event.

What does Lesley mean when she writes that she will "model this event?"
Let's talk about the various parts of the model.
  What part of the set-up is the bike?
  How will she represent the mass of each biker?
  How will she make the cart move?

> Ss independently label the Figure with the event analogues to the parts of the model.
> Ss and T share and compare their ideas.

How is this a good way to scientifically model the biking event?
  In what ways is the model different from the actual biking event?
  Do the differences mean the model is inaccurate?

How do you think Lesley used the materials to create 3 different masses on the cart, and 3 different amounts of force pulling the cart?
Why do you think she wanted to investigate with 3 diff. amounts of force?
What do you think about Lesley's decision about how to time the cart?
What do you think Lesley means when she says:
  "I ran a number of trials / with each amount of force and mass."?

> Ss pantomime Lesley's investigative activity, and list what kind of information she needs to record for each trial/each condition.

Do you agree with Lesley's way of telling when she had a "good measurement?" Why or why not?
  What do you think the phrase "good measurement" means?

Scientist: Lesley Park Date: 8/18/03 Page: 2

Table 1. The effect of changing mass and force on the motion of a cart.

	Mass (# blocks)	1	1	1	2	2	2	3	3	3
	Force (# washers)	1	2	3	1	2	3	1	2	3
TIME (*seconds*)	Trial 1	1.32	1.17	0.99	1.60	1.23	1.04	1.65	1.28	1.15
	Trial 2	1.27	1.08	1.04	1.52	1.15	1.11	1.74	1.25	1.21
	Trial 3	1.25	1.19	0.95	1.45	1.17	1.07	1.67	1.32	1.19
	Trial 4	1.23	1.13	1.08	1.39	1.20	1.13	1.71	1.30	1.22
	Trial 5	1.30	1.09	1.01	1.48	1.24	1.10	1.69	1.30	1.20

Let's look at Lesley's data table.

Have you ever seen a table like this? What do you notice about this table?

What does the title of Table 1 tell us that Lesley is investigating?

What information is provided in the table? How do we tell?

Let's start with the first row. A row refers to information that is organized and read from left to right. You can remember this by the "r" of "row" and the "r" of "right." This cellophane strip shows a row.

Looking at the first row, what information is provided?

This first cell is a heading for the row. It tells us what is being measured, and in parentheses, we are told the units for the measurement.

What units did Lesley use to record the amount of mass?

What do these different masses represent in the bike race?

Whenever she had one block on the cart, that represented what?

[*the lightest person*] Repeat question for each amount of mass.

Let's add our own row above the row that tells us about mass, and write in the name of the person represented by each amount of mass.

Now let's look at the second row. What information is provided in this row?

What units did Lesley use to record the amount of force?

What do these different force represent in the bike race?

Whenever she had one washer on the string, that represented what?

[*a little bit of pedaling*] Repeat question for each amount of force.

How does this information compare what we wrote in our notes yesterday aboutwhat we thought Lesley should document?

Beginning in the 3rd row, there's a different kind of information.

What type of information is in these rows? [*Trials*]

What do the numbers in the rest of this row mean? Where is there information in the table that tells us what these numbers mean?

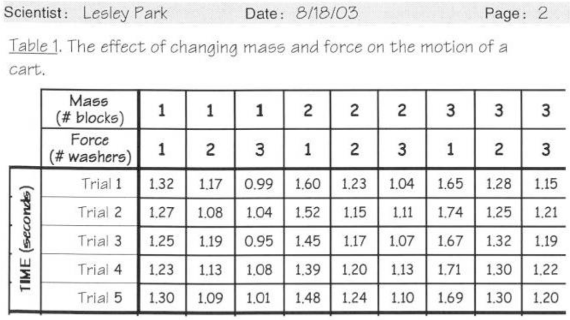
To the left of these rows is a heading that gives us information about what these numbers mean: Time in seconds.

The way that we read these numbers is:

1.32 seconds or One and 32 hundredths of a second

1.32 seconds would be understood by someone who knew about decimal #s.

If a person doesn't know about decimals, you would want to read the number as "one and 32 hundredths of a second."



Scientist: Lesley Park Date: 8/18/03 Page: 2

Table 1. The effect of changing mass and force on the motion of a cart.

	Mass (# blocks)	1	1	1	2	2	2	3	3	3
	Force (# washers)	1	2	3	1	2	3	1	2	3
TIME (seconds)	Trial 1	1.32	1.17	0.99	1.60	1.23	1.04	1.65	1.28	1.15
	Trial 2	1.27	1.08	1.04	1.52	1.15	1.11	1.74	1.25	1.21
	Trial 3	1.25	1.19	0.95	1.45	1.17	1.07	1.67	1.32	1.19
	Trial 4	1.23	1.13	1.08	1.39	1.20	1.13	1.71	1.30	1.22
	Trial 5	1.30	1.09	1.01	1.48	1.24	1.10	1.69	1.30	1.20

Now we've talked about all the information in the table, but we haven't put it all together. To do that we need to look at how the columns and rows go together.

A column refers to information that is organized and read from up to down. This cellophane strip shows the first column with data; that is, with times that Lesley recorded telling how long it took the cart to get to the end of the table.

[put cellophane strip over first column with data]

What information does this column tell us about what was done and what happened in the investigation.

Use transparency of Figure 1 without blocks on cart or wachers on string.

- select one condition for the table
- have Ss silently identify what the investigative set up would look like for that condition
- have Ss circle the fastest time and draw a box around the slowest time
- select one student to draw the condition on the transparency, and draw a circle and box around the fastest and slowest times
- check whether other Ss agree or disagree.

Repeat for two other conditions.

When she was repeatedly doing the same thing -- that is, in each column, when she had the same amount of force and mass but ran five trials -- why do you think the times were different?

What could have happened that would have caused differences in the times?

Scientist: Lesley Park Date: 8/18/03 Page: 2

Table 1. The effect of changing mass and force on the motion of a cart.

	Mass (# blocks)	1	1	1	2	2	2	3	3	3
	Force (# washers)	1	2	3	1	2	3	1	2	3
TIME (seconds)	Trial 1	1.32	1.17	0.99	1.60	1.23	1.04	1.65	1.28	1.15
	Trial 2	1.27	1.08	1.04	1.52	1.15	1.11	1.74	1.25	1.21
	Trial 3	1.25	1.19	0.95	1.45	1.17	1.07	1.67	1.32	1.19
	Trial 4	1.23	1.13	1.08	1.39	1.20	1.13	1.71	1.30	1.22
	Trial 5	1.30	1.09	1.01	1.48	1.24	1.10	1.69	1.30	1.20

How do I look for patterns in the data? How do I deal with having multiple trials for each amount of force and mass? I talked with colleagues down the hall to get ideas. Marissa told me about a strategy by a famous researcher, Dr. Tukey. He had a simple way to determine a single value to stand for a group of numbers. With his procedure I had a way to find one number that would stand for all five trials!

Tukey's first step was to cross out the numbers that were likely to be the least accurate. In my case, this meant the values in the hundredths-of-a-second column. Tukey's next step was to put the values in order, so I ordered the times from fastest to slowest. Finally, Tukey said to select the value in the middle, which in my case was the third value. Figure 2 shows my use of this procedure for the set of trials from timing the cart with 1 block pulled by 1 washer.

1.3~~2~~		1.2		1.2		
1.2~~7~~		1.2		1.2		
1.2~~5~~	⇨	1.2	⇨	$\boxed{1.2}$	⇨	1.2
1.2~~3~~		1.3		1.3		
1.3~~0~~		1.3		1.3		

What do you think about the idea of trying to get one value to stand for a set of trials?

Let's call the result Lesley got for the first column of data, a summary time. And let's write that summary time at the bottom of that column.

So, column 1 is done for us, let's move on to Column 2 and try Tukey's procedure ourselves. For the this column, we'll do exactly as Lesley did.
- let's first rewrite the column numbers, in a column (demonstrate)
- now, let's cross out the number in the hundredths place
- next, we write our new numbers in a new column, but we put them in order
-finally, we circle the middle number, and that is our summary time
-write what you got at the bottom of the times in Column 2

Let's do one more together . . .

Now, do the rest of the columns yourself, and let's see how our results compare.

Have Ss share results, write on transparency to make a summary table.

Scientist: Lesley Park Date: 8/19/03 Page: 3

Table 2 shows the summary of my data. Now I had a manageable number of values to look at to see whether there was a pattern in my data.

Table 2. Summary table of the effect of changing the amount of mass and force on the motion of a cart.

Mass (# blocks)	1			2			3		
Force (# washers)	1	2	3	1	2	3	1	2	3
Time (seconds)	1.2	1.1	1.0	1.4	1.2	1.1	1.6	1.3	1.2

There are two claims I feel confident to make from my data:

- the greater the amount of force making an object move, the faster the object goes.
- the greater the mass of an object, the slower it moves in response to the same amount force.

These variables have opposite effects. So, when I'm riding my bike with my usual pedaling, and have a heavy backpack on, I will go slower. But, I can go faster if I pedal harder, and maybe I can pedal hard enough to go the same speed as I do without a heavy backpack. I think that has something to do with why we tied in the race.

I reorganized my data so that I could more easily compare the times for the cart with different amounts of force and mass. And I revised the headings in the table so that the words represented the situation in the bike race.

How does Lesley's summary table compare with our own?

Now we'll use the summary table to see what we can conclude from the data. But before we do this, we need to be sure about the questions that Lesley investigated. That will help us to decide how to look for patterns in the data.

Sample across the children's entries and post the two questions:
How does the amount of force on an object affect its speed?
How does the mass of an object affect its speed?

Now, let's look at the summary table, and for each question, determine whether we can write a claim. A scientific claim is a statement about the world that you think is accurate. We would be able to state a claim if there is a pattern in the data, and the pattern is described in the claim.

For example, the first question is about force. As the amount of force changes, what happens to the time?
Does the time stay the same or change?
When it changes, does it change in the same way as the force changes, or in a different way?

T leads Ss to write a claim about force and motion, then has the Ss write a claim about mass and motion.

Sample across the children's entries and post their claims for the question.

How do Lesley's claims compare with our own?

What does Lesley mean when she writes that "these variables have opposite effects?"

What does Lesley mean when she says that she feels "confident" about the two claims she has made? [*She means that she feels sure that these are accurate claims.*] Do you feel confident that these are accurate claims? Why or why not? Is there something that would make you more confident?

In this paragraph, Lesley use the claims she has made about the effect of force and mass on the motion of objects to think about biking with her backpack. Do you agree with her thinking? Is this kind of comparison a helpful thing to do as a scientific thinker?

In the last sentence, Lesley writes that she thinks she now has an idea about why she and her friends tied in the race. What do you suppose she is thinking? How can we use these claims to think about the bike race?

Scientist: Lesley Park Date: 8/19/03 Page: 4

Table 3. Summary table of modeling the effect of a person's mass and pedaling force on the motion of a bike.

		People's Weight		
		light	medium	heavy
Pedaling Force	slight	1.2 sec.	1.4 sec.	1.6 sec.
	moderate	1.1 sec.	1.2 sec.	1.3 sec.
	strong	1.0 sec.	1.1 sec.	1.2 sec.

If we tied in the bike race, then our times to the park were the same. In Table 3, several times are the same, and in one case they were the same for three different amounts of mass and force. Of course, these times are much faster than the time it took us to race to the park, but I can imagine what might have happened. If the first column stands for Felicia, she would tie me in the bike race if her pedaling force was less than mine. If the last column stands for Jermaine, he would tie me in the race if his pedaling were greater than mine.

For us to tie, Felicia must not have been as strong at pedaling as she thought when we raced. And Jermaine must have pedaled hard enough to make up for his extra weight, but not hard enough to win the race. I wonder what they will think about my investigation of this problem? Will they be convinced that I've reasoned through these data correctly? I'll share my results with them tomorrow and see what they think.

How can we use this organization of the data to figure out what happened in the bike race? Now, of course, these times are much faster than it took for the actual bike race, but in Lesley's model of the bike race, whose times are reported in the first column? [*Felicia. Label on trans.*] Whose times are in the second column? [*Lesley.*] And the third? [*Jermaine.*]

Let's look closely at the data in Table 3. What observations can we make from this organization of the data that would help us to explain how the three friends tied in the bike race?
[If needed - "If the three friends tied, they all must have taken the same amount of time. What were the conditions when the cart took the same amount of time to travel?"]

How does Lesley's thinking compare with our own thinking about why the three friends tied?

What do you think about Lesley's investigation of the bike race and about her conclusions?

What do you think about using notebook texts as a way of learning science?

Our last notebook entry for this notebook text will be for the purpose of writing about the ways in which the notebook text was helpful to our learning about force, mass, and motion, and about conducting scientific investigations, as well as writing about what would have been helpful to our learning about force, mass, motion, and scientific investigation.

APPENDIX G: LESSON PLANS FOR WEEK 2 SECOND-HAND INVESTIGATION

Teacher's Guide - MOTION 03 Notebook Text - RAMP **ROLE-NSF**

Teaching with the Notebook Text:

Each page of the notebook text is handed out separately, and as needed.

In this guide, on the left size is a minature version of the students' text. On the right side is information to support teaching with the notebook text. There are two types of information:

- prompts that provide questions or tasks that the teacher presents to students to maximize learning from the text. These questions are suggestions that are intended to signal the kind of thinking with the notebook text that is desired. There are more questions/tasks written per page than need be asked, so that point is not to ask them all, but to get the kind of dialogue suggested by the prompts.
- prompts written within boxes that are stimuli for student writing in response to the notebook text.

Intro to Notebook Text genre for children who have had 1st-hand experiences investigating motion on a horizontal plane:

Last week, we investigated how changing the mass and force on a cart changed the time it took for the cart to travel. We call the kind of investigation we did a 1st-hand investigation. Today, we are going to start what is called a 2nd-hand investigation; that is, we are going to read the notebook of a scientist who is reporting on her 1st-hand investigation. Thinking about our 1st hand investigation and about the notebook that we kept as we were investigating last week, what do you expect you will find in this scientist's notebook?

[*elicit and record on poster paper the children's thinking*]

About writing

In addition to reading the notebook of a scientist, we will continue to keep our own scientific notebooks.As we read and discuss the scientist's notebook, we are going to use our notebooks to record our own thinking. This will enable us to compare our ideas with the ideas of the scientist.

Hand out Page 1 of Lesley's notebook. "This is part of the notebook of a scientist named Lesley Park."

Q - What do you notice about what's in Lesley's notebook?

Intro to Notebook Text genre for children who have had 2nd-hand experiences investigating motion on a horizontal plane:

Last week, we read and thought about Lesley Park's investigation regarding how changing the mass and force on a cart changed the time it took for the cart to travel. We called this kind of investigation a 2nd-hand investigation. Today, we are going to start a new 2nd-hand investigation of a new problem that Lesley will be investigating. Before we look at Lesley's notebook, what are you expecting to find in her notebook?

[*elicit and record on poster paper the children's thinking*]

Scientist: Lesley Park Date: 9/2/03 Page: 1

On Saturday, when I went skateboarding with Tony, a strange thing happened. We raced down a hill, and even though I'm lighter and thought I would win easily, we tied! We both started at the same time and at the same place on the hill. And, we raced sitting down on our boards so our leg strength would not affect the race. I asked Tony whether he pushed with his feet at the start, but he said he ran a fair race. We raced three more times, and even switched starting places on the hill. That way, we could rule out differences in the road that might have affected our times. But in each race, we reached the bottom of the hill together. Why did we tie?

To answer my question, I chose to model this event to investigate it. I needed something to stand for the hill, and something that could move like a skateboard. I also needed a way to represent the differences in the skateboarders. Figure 1 shows the set-up I used to investigate how changing the amount of mass affects how long it takes an object to roll down a ramp.

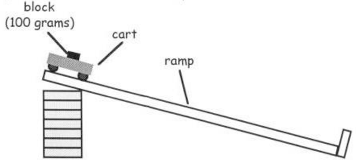


Figure 1. Modeling the skateboarding race.

I decided to use a 100 gram block for me and two, 100-gram blocks for Tony, who is about twice my weight. I also planned to run several trials in order to get a good time measurement for each amount of mass. Finally, I planned to run trials with three blocks on the cart. If mass affects how long a cart takes to roll down a ramp, having a large difference in mass should help me observe that. Table 1 shows my observations.

What does Lesley describe in this first paragraph of her notebook?
Why do you think Tony and Lesley sat on their skateboards? How would that affect their motion down the hill compared to standing up?
Why did Lesley think that she would get to the bottom of the hill first?
Did you agree with Lesley's prediction that she would get to the bottom first? Why? Why not?
Why did Lesley ask Tony if he had done any pushing?
Why do you think it was a good idea for Lesley and Tony to race more times down the hill?
What do you think Lesley means when she writes that they "switched starting places on the hill?" Was this a good idea? Why or why not?
What is puzzling Lesley?
What would you tell Lesley if she asked you why you thought she and Tony got to the bottom of the hill at the same time?

What does Lesley mean when she writes that she will "model this event in order to study it?"

Ask the students to label Figure 1, identifying the various parts of the model

Let's talk about the various parts of the model. What part of the set-up is the hill?, ... the skateboard?,...whose "different masses" is she writing about? What is she using to represent the mass of Tony and herself?
What do you think of Lesley's model?
Is this a good way to model the skateboarding problem? Is there any way that you think the model could be better? more accurate to the actual event?)
How do you think Lesley will conduct her investigation using these materials?

How did Lesley actually conduct her investigation with these materials?
How did our ideas about how to conduct the investigation compare with Lesley's actual investigation?
Why does Lelsey say whe will run several trials with ech mass?
How many different masses did she use in her investigation?
Why is she investigating with a mass of three blocks when there were just two skateboarders and Tony is twice as heavy as Lesley, but not three times as heavy?
What do we predict her results will be for each amount of mass that she investigated?

Scientist: Lesley Park Date: 9/2/03 Page: 2

Table 1 Time of Travel Down a Ramp

	Mass (g)	100	200	300
TIME (seconds)	Trial 1	2.34	2.35	2.33
	Trial 2	2.39	2.38	2.37
	Trial 3	2.34	2.33	2.35
	Trial 4	2.31	2.38	2.35
	Trial 5	2.35	2.32	2.33

The pattern that I see with these data is that the cart takes about the same amount of time to go down the ramp each time. And that happens even though the cart carries different amounts of mass. So, these data do match the outcome of my race with Tony. It seems that mass does not affect the time it takes an object to roll down a ramp. How could that be? I asked my colleague Becky to help me think about this question.

I told Becky about the race and my question. I told her how I modeled the event, and showed her my data. When she asked how I investigated, I told her that I carefully used the materials in the same way each time, and ran multiple trials. I said that I systematically changed the mass, and carefully timed the travel of the cart.

Becky then asked what I thought about the force that caused the cart to move. I told her I assumed that the force of gravity was the same on both Tony and me. She wondered whether it could be different. I did not think so, but I couldn't be sure because I didn't measure it. What if the force of gravity were different for different amounts of mass?!

I wondered how I could measure the force of gravity on the cart. Becky and I discussed several possible methods. I decided to try two different procedures. That way, I would give myself the best chance to tell whether the force of gravity was different for different amounts of mass.

What information does Lesley provide in her data table? *amount of mass, number of trials, time it took for the cart to reach the end of the ramp*

What sense can we make from all these numbers?

Looking at the times for the cart when it had 100g of mass, how long would you say it took the cart to reach the end of the ramp?

Does anyone know what mathematical tool we can use to answer that question? *determine the median time for the trials*

Let's find the median time it took the cart to travel down the ramp with each amount of mass. [have students record on their copy of the text]

How do these results compare with our predictions?

What does Lesley conclude from her results?

How does Lesley's conclusion compare with the claim that we made from her data?

Why do you suppose Lesley decided to consult with Becky?

If Lesley decided to consult with us, what could we do to help her think about her question?

What does Becky ask Lesley to tell her about?

Why do you think she asked her to do that?

Read first sentence only and then stop to say: "Let's talk about the force that caused the cart to move.' What do you think is the force causing the cart to move."

What force does Lesley think is causing the carts to move down the ramp? How is Lesley thinking about how the force of gravity compares when it is pulling on objects of two different amounts of mass. Do you agree with her thinking?

Let's do a thought experiment: If (small child) and I were a the top of a hill on two skateboards and we needed someone to hold us in place so that we would not roll down the hill, who would you rather hold back? Why? What does that tell us about the force of gravity?

What are your ideas about how Lesley can measure the force of gravity? Link to the thought-problem... How could they measure the force it takes to keep me - and the child - from rolling down the hill?

Scientist: Lesley Park Date: 9/3/03 Page: 3

The idea for the first method came from thinking about how Tony and I each applied a force with our feet to hold us in place at the start of the race. If two people had held us in place instead, what would they have felt? Would it take the same amount of force to hold me in place as it would take to hold Tony in place, or would it be different? I thought a spring could be used to measure this force (see Figure 2). A spring holding a cart at the top of a ramp should stretch in response to the force on the cart. I can measure that force by measuring how much the spring stretched.

Figure 2. The spring method for measuring the force of gravity on a cart.

The idea for the second method came from thinking about the force it took Tony and I to get up the hill. On flat ground, it does not take as much force to get a skateboard moving as it does to go up a hill. And, it takes more force to skateboard up a higher hill than a lower one. That gave us the idea to measure the amount of force it takes to pull a cart to the top of a ramp. We placed a cart at the bottom of a ramp, and attached a string to it that was just longer than the ramp. We added washers to the end of the string until the cart began to move up the ramp (see Figure 3).

Figure 3. The washer method for measuring the force of gravity on a cart

Begin this page by asking the students to summarize what Lesley has written about thus far (encourage looking back in the notebook: the race,the surprising outcome due to weight difference, Becky's question about force, Lesley's question about how to measure force

In the first method, how does Lesley measure the force on the cart at the top of the ramp?

Do you think this is an accurate way to measure the force of gravity on the cart? Why or why not?

What do you predict will happen to the length of the spring as Lesley adds more mass to the cart on the ramp?

If the spring stretches .5 cm with one block, what do you predict will happen when the cart has two blocks?

What will that result tell us about the force of gravity on the cart?

In the second method, how does Lesley measure the force on the cart at the top of the ramp?

Do you think this is an accurate way to measure the force of gravity on the cart? Why or why not?

What do you predict about the number of washers it will take to move the cart as Lesley adds more mass to the cart on the ramp?

Let's say that it took 10 washers to pull the cart with one block up the ramp, how many washers do you predict it would take to move the cart with two blocks?

What will that result tell us about the force of gravity on the cart?

Scientist: Lesley Park Date: 9/3/03 Page: 4

My data from these two methods for measuring the force of gravity on a cart on a ramp are shown in Tables 2 and 3.

Table 2 Force measurements from spring method

Mass on Cart (grams)	Spring Length with blocks (centimeters)	Spring Stretch* (centimeters)
100	10.9	0.9
200	11.6	1.6
300	12.5	2.5

*spring length holding cart without blocks = 10cm

Table 3 Force measurements from washer method (1/2-inch washers)

Mass on Cart (grams)	Washers on String
100	5
200	11
300	16

Claims

- The greater the mass, the greater the force of gravity on it at the top of a ramp.
- The force of gravity increases by the same amount that the mass increases: twice the mass has twice the amount of force on it; three times the mass has three times the amount of force on it.

I was wrong about gravity! The force of gravity is greater on objects that have more mass. That means that my investigation of the time it took the cart to go down the ramp with different amounts of mass was not a fair test. Each time I changed the amount of mass on the cart, I also changed the amount of force on the cart. So, I was testing the effect of changing two variables at the same time, not just one.

What information is provided in Table 2?
title, amout of mass on cart, length of spring, # washers on string
What do these results tell us about the amount of force on the cart?
about the force of gravity on objects of different mass?

What claim can we make from the data in Table 2?

How does Lesley's claim compare with our own claim?
Why does Lesley say that she was "wrong about gravity"?
What does Lesley mean when she says that her investigation was not a fair test."
What was "unfair" about her investigation?
How does this new information about the force of gravity help us to understand the skateboarding problem?

How did the force of gravity compare for Tony and for Lesley?
How does that help us to understand the outcome of their race down the hill?
What would happen if Lesley put on a heavy backpack and then skateboarded down the same hill? What do you predict her time would be? How would you explain your prediction of her time?
What would you say about whether mass affects the motion of an object on a ramp or a hill?
mass does affect the motion; it affects how much force moves the object

Lesley is surprised about this result for the force of gravity. Are you surprised?
How would you answer Lesley's question about the force of gravity adjusting?
[*this is not something that scientists really understand*]

What does Lesley mean by her investigation not being a fair test?

What other questions might Lesley investigate regarding the effects of motion and force on objects traveling down a hill or ramp?

Scientist: Lesley Park Date: 9/3/03 Page: 5

Also, my investigation showed that the amount of change in mass and the amount of change in force were about the same. If one cart has twice as much mass as another, then that cart has twice as much force on it as well.

Even though my investigation was not a fair test, the results do help me understand what happened at the park. I knew that Tony and I did not have the same mass, so I thought that would make a difference in the race. But I did not know that Tony and I did not have the same amount of force pulling us down the hill. So, mass did influence what happened in the race because Tony's greater mass also meant the force of gravity was greater on him. Tony had more mass to move, but he also had a larger force to make him move. I had less mass to move, but I also had less force to make me move. The force and mass differences sort of canceled each other out, so we reached the bottom of the hill in the same amount of time.

So, what is going on with gravity?! I want to share these results with my colleagues. I wonder what they think about gravity, and what they will think of my results?

How confident are you about Lesley's claim that gravity increases by the same amount as force increases? [twice the mass has twice the force]

How does this observation help us to understand the outcome of the skateboard race down the hill?

How did the force of gravity compare for Tony and for Lesley (given the differences in their mass)?

In this investigation, Lesley writes that the force and mass cancelled each other out. How does this compare with our explanation about how the three bikers who were of different sizes, tied in the bike race to the park?

Conclude by asking children to write to Lesley about learning from her notebook text. How was her notebook helpful to your learning? What's the best part of her notebook? What was the least helpful part of her notebook?

APPENDIX H: DESCRIPTIONS OF TEACHING PRACTICES THAT ARE CONSISTENT WITH GISML INSTRUCTION

Range of Teaching Practices consistent with the Principles of GIsML Instruction

ENGAGE Phase

TEACHER PRACTICE	ILLUSTRATION
Stimulate Ss' curiosity about a particular aspect of the physical world.	Ss state what they wonder about a particular aspect of the physical world.
Activate Ss' prior knowledge specific to the targeted <u>content</u> goals for the program of study.	T administers pre-instruction assessment in topic area. T prompts Ss to state what they think they know about a particular aspect of the physical world.
Activate Ss' prior knowledge relative to the targeted scientific <u>reasoning</u> goals for the program of study.	T prompts Ss to state what their evidence is for their knowledge; i.e., how they came to learn what they know.
Prompt Ss to be mindful of scientific ways of thinking and acting.	T asks Ss to identify whether outcome was determined via a fair test.
Mediate Ss' thinking regarding ideas about question/phenomena toward a set of specific statements - claims - about the question/phenomenon.	T prompts Ss to make specific claims regarding a particular question or phenomenon in terms of how the world works.
Guide Ss to evaluate what they would like to do given claims/questions that have been determined. Guide Ss to determine what is possible in a first-hand way considering materials that are available to students.	T shows Ss materials (e.g., a collection of objects of different thickness, color, transparency), and asks Ss how they could work with them to determine answers to specific focus questions.

Prepare to INVESTIGATE Phase

TEACHER PRACTICE	ILLUSTRATION
Mediate Ss' thinking about how to investigate claims. Provide materials/equip. to support Ss in generating ideas about their inquiry.	T guides students to determine what materials are best to use (and in what ways) to address the focus question and how they can investigate with those materials. Ss examine materials to determine how they might be used in investigation.
Guide Ss in developing effective strategies for investigation. Show Ss how to use particular materials.	T uses a set of materials that will be used during the investigation (e.g., flashlight, one solid) as props to support guidance via questions and statements to help students develop effective procedures for determining whether light is reflected and/or transmitted through the solid objects in the set.
Guide Ss in developing means for effectively collecting & recording data. If needed, provide a model to help students organize data collection; encourage Ss to modify as needed.	T asks Ss to share ideas about how to keep track of their observations, how they are going to make sure the range of desired observations are made (e.g., looking for evidence of reflection, transmission, and absorption of light.) T distributes sheet with example table for recording observations, and questions Ss they might modify the table to support data collection.
Mediate Ss' thinking regarding standards for collecting and recording data.	T monitors Ss' planning activity for attention to precision and accuracy of measurements; what will be possible to document.

Range of Teaching Practices consistent with the Principles of GIsML Instruction

INVESTIGATE Phase

TEACHER PRACTICE	ILLUSTRATION
Ascertain Ss' ideas about the phenomenon under study.	T asks Ss what they are observing.
Ascertain Ss' ideas about patterns in the data.	T asks Ss about similarities and differences in their observations.
Ascertain Ss' ideas about relationships suggested by the patterns in the data.	T asks Ss what sense they are making about specific similarities and differences (noted by the T) in their observations.
Monitor procedures used by Ss to investigate. • T notes ineffective procedures. • T questions Ss about their findings as a means to promote their realization of ineffective procedures. • T provides direction and scaffolds Ss in utilizing effective procedures.	T comments to Ss the observation that the way they measured a particular variable was different from one time to the next and asks whether the Ss thinks that makes a different in the reliability of their results. T suggests Ss use one particular strategy they invented than others for measuring a particular variable.
Monitor Ss for finding patterns in data • Ask Ss whether they have looked for patterns and how they have done that. • Scaffold Ss in finding patterns by prompting them to describe similarities and differences in their data. • Scaffold Ss in using data table or similar organizer to help them see patterns by assisting them in identifying whether they have accurately utilized the organizer.	T points to particular data (reflecting a similarity or difference, depending upon which is more important in the moment) and asks Ss to describe how they are similar/different. T points to key aspect of a phenomenon or observations of a phenomenon (e.g., the angle of the lines showing the path of light) and asks Ss to describe what they see.
Initiate the propagation of ideas (use of materials, procedures, concepts) across groups.	T comments to a group that they might want to consult with another group to share their strategies or learn about the other group's.

Prepare to REPORT Phase

TEACHER PRACTICE	ILLUSTRATION
Monitor Ss for constructing relationships based upon patterns in the data. • Press Ss to form conclusions from patterns in data; conclusions include claims and evidence for claims. • Provide Ss time to prepare representation of findings to share with classmates.	Tell Ss that conclusions include both a claim and evidence for the claim. Support Ss in clarifying their claim statement, support them in constructing more general statements (e.g., light is reflected by light-colored objects). Press Ss about their confidence in their conclusion – have they considered all the data – looking for confirming and disconfirming evidence.
Monitor Ss for having complete and effective representations. • Prompt Ss to draw as well as write to show ideas • Press Ss to evaluate their work for its completeness and effectiveness in communicating findings/conclusions.	Remind Ss that enough information needs to be shared for others to replicate their investigation.
Mediate discussion of norms for public sharing for science (e.g., what will be expected to be shared, i.e., claims, evidence).	T prompts Ss to make suggestions about what will be helpful in representations of claims and evidence to enable them to understand one anothers' reports.

Range of Teaching Practices consistent with the Principles of GIsML Instruction

REPORTing Phase

TEACHER PRACTICE	ILLUSTRATION
Orchestrate presentations in terms of order and pacing.	T may determine who begins the reporting and/or who should come much later.
Ascertain Ss' ideas about patterns / relationships.	T prompts community to restate the relationships communicated by the presenters; T prompts comparisons of findings across posters.
Model thinking/reasoning regarding evaluating others claims, evidence, procedures, reasoning.	T explicitly acts as other community members, thinking out loud about how he/she understands a presenter's data and evidence, i.e., conclusion.
Monitor for relationship between what Ss report and what they experience; look for discrepancies in: • claims/evidence shown & what report orally; • evidence reported for claims made; • evidence reported and what was possible to observe; • evidence/claims reported given what Ss actually observed, which T knows to be much broader than what reported to class.	T uses his/her own recollections of Ss' data and what is reported to the community to selectively raise questions about the content of what Ss' report, in cases where discrepancies are noted.
Hold all Ss accountable for thinking about: • similarities and differences regarding claims, evidence, procedures, reasoning processes. • confidence in findings of self & others (i.e., how convincing was evidence for claims, other findings).	T assigns community members with intellectual roles: a) monitoring statement and clarity of claim, b) monitoring statement and clarity of evidence c) monitoring clarity and connection of claim and evidence (confirming and disconfirming)
Hold presenters accountable for clear communication.	Community members question presenters as needed.
Hold community members accountable for: • promoting clarity of presentation. • reflecting completeness of presentation or quality of the case made for claims. • effectively playing designated intellectual roles.	T presses community members to play their roles.
Privilege targeted language, ideas, relationships, etc.	T encourages the use of particular language introduced by Ss; T adds language to public glossary.
Opportunistically introduce scientific language. Opportunistically suggest new ideas to consider. Opportunistically suggest new relationships to consider.	T introduces new language to use for ideas expressed by students; T suggests ideas, methods, relationships to Ss when it will help advance the Ss' thinking in a way that builds on that thinking or kernels of their ideas toward the desired understanding.
Ascertain community's decisions about the claims.	T polls Ss to determine which claims generate consensus and records on "Class Claims" sheet. T designates which claims are controversial and need further investigation. T indicates (Cycle 2 and later) which claims have been ruled out.

APPENDIX I: SAMPLE FROM PILOT STUDY OBSERVATIONAL NOTES

MR. CANNON, 1st hand only group
10/20/03

Passes out folders – 5minutes
Reads from script – telling data design, explaining a scientist's notebook and how they will use notebook.
T: "Let's imagine there is a bike race between Lara – looking at script frequently as he talks about race where he and Lara tie.

What do people think about that?
> Ss: How big are wheels, are you going down a hill?
> Sandra: you tie because you have the same source of energy
> S: says something about who will win

T responds: who do you will predict will win.
Girls respond Mr. Cannon because he is bigger.

T: How do you think that can happen that we can tie?

Ted: Maybe because you're bigger you can pedal faster.
Mr. Cannon: Mm hmm…OK any other ideas.

How would a scientist investigate how they tie?
No response.
Could we just keep running the race over and over and over again?
S: No because one of you might get tired and things would keep changing.
Linda: inaudible.
Mr. Cannon: Oh. OK.

So doing it over and over we'll start getting different outcomes because different things are happening if someone got tired…

S: response.
Mr. Cannon: Oh Okay. A scientist would model the race. Ideas about model?

S contributions: an example. A thing. A fake one and a real one – the fake one is a model of the real one.

Mr. Cannon: Oh ok. Then reads from script what model is. Paraphrases – using Travis's words but doesn't credit him.

Mr. Cannon passes out table and puts on overhead:
"What are some THINGS from the race? What did the race involve?"

S contributions: Bike, flat surface, same tires, pedaling, start line, finish line (contributions with t prompting)

Mr. Cannon takes out each piece of the bag separately and introduces what they are to students.
Mr. Cannon: What of these materials will be the bike?

Demonstrates each object as he sets it up and identifies on table what it represents. Students copy down

Gets to third column – checking off what would affect the race outcome. Treats as a checklist, going through quickly.

Gets to final column – what would we want to change? (No discussion of why we don't want to change it).

Responds to most of them saying – we could change it but we're not going to.

"We need to change the pedaling to see what happens."

Mr. Cannon: We need to think about two things. Reads questions from notes:
How does changing the ___ affect the time it takes the cart to get to the end of the board?

What's the other thing we're going to change?

S: the string
Mr. Cannon: Actually it's the number of washers. Writes second question on overhead.

Students respond "# of block" and "# of washers"

Ted makes complicated observation that washers are heavier than blocks so they'll pull the cart anyway.
Mr. Cannon: respond that this gets us to the next question. So how do we change this question so it's with the actual?

Ted: states –
Mr. Cannon responds. Does everybody agree with that? Sounds like a good question (no discussion ensues).

Mr. Cannon writes on overhead:
How does changing the people change the time it takes for the cart to get to the end of the board?

APPENDIX J: OBSERVATION SUMMARY SHEET

CONDITION – TEACHER NAME, DATE, GIsML PHASE (TIME)

Students engaged in deriving a testable question.	
Students engaged in considering the systematic manipulation of variables.	
Students engaged in considering the rationale for running multiple trials.	
Students engaged in modeling the phenomenon.	
Students engaged in measuring variables.	
Students engaged in organizing the recording of data.	
Students engaged in interpreting a data table.	
Students engaged in identifying patterns in a data table.	
Students engaged in comparing claims.	

Mass determines who will win.	
Force determines who will win.	
The mass-force relationship determines who will win.	
Miscellaneous	

APPENDIX K: TRANSCRIPT ANALYSIS SAMPLES WITH DEPENDABILITY CHECK

Analytical Lens	Guiding Question	Transcript Excerpts	Analytical interpretations – Khasnabis	Analytical interpretations – independent rater
Participant structure	If students were perceived as having ideas that were either worthwhile or not worthwhile, what features of the instructional setting (curricular attributes, teacher moves/characteristics, or student moves/characteristics) potentially positioned the student in this way?	Example 1 (*Report* rich case, second-hand investigation): Ms. Allen: If you are trying to illustrate what the setup looked like when Lesley was running a particular trial, what information do you need to draw on this diagram? Is your hand up Bethany? Sort of? Why don't you give it a try? Bethany: You might need to draw the table (inaudible) and um draw just like what she did. Ms. Allen: Can you say, what do you mean "what she did"? Bethany: You could draw the cart moving like um place to place until it just stops. And then you don't even show the washers. Ms. Allen: Ah. Now why would you not show the washers? Bethany: Because if you're actually (inaudible) It wouldn't make sense for the washers to be up (inaudible) Ms. Allen: Oh that is such a good point. But do you notice that on our illustration the washers the string goes all the way down? OK? So that's a very smart thing to be thinking about. The washers are no longer going to be here. You're absolutely right. But here the string has dropped and so you can, in fact, draw your washers. To show how many washers, how much force.	Ms. Allen positioned Bethany as a student who has worthwhile ideas. She gave Bethany opportunities to elaborate upon her intended meaning when she was unclear, verbally complimented Bethany's thinking, and acknowledged that even though Bethany's response was not the desired response, it was still a sensible and even insightful response.	Bethany is perceived as having worthwhile ideas. Ms. Allen acknowledges that Bethany is considering the setup from one angle while she is looking at it from another. She facilitates Bethany's viewing the setup from different angles without disregarding her comment and compliments her.
		Example 2 (*Report* lean case, first-hand investigation): Ms. Baker: What's the lowest time here? Kurt, I'm sure you know this one. Which is the lowest time in this column? Kurt: Um, 0.73. Ms. Baker: Nope. Do you know Ellie? Ellie: Um, 1.42. Ms. Baker: Yeah. 0.42 is the lowest. Ellie: Yeah. 0.42 Ms. Baker: What's next? What's next highest? Ellie, you tell us again. Ellie:1.46. Ms. Baker: It's zero. Ellie: I mean 0.46 Ms. Baker: 0.46. So Kurt can you tell what's next? That's the lowest. That's the next low. Kurt: 0.73 Ms. Baker: Nope. Not yet. Mira? Mira: Oh, never mind.	Kurt was positioned as a student who did not have worthwhile ideas. Ms. Baker assumed he would be able to respond correctly to the questions she posed, but he repeatedly answered incorrectly. This had the effect of positioning Kurt as a student who could not get the right answer for questions that were perceived as "easy" and for questions that other students knew the	Kurt is perceived as not having worthwhile ideas because he repeatedly gets the answer wrong even when other kids get the answer right. The teacher just asked Kurt questions, but didn't correct him or say why he was wrong or how to figure out the right answer. So Kurt just kept getting the answer wrong.

		Kurt: 0.70 Ms. Baker: Nope, try again Kurt. (pause) Mira, can you help him out? Mira: 62. Ms. Baker: Yes. Again, the third number is the one I circled.	answers to. Ms Baker also took no steps to help Kurt derive correct answers and potentially position him as knowledgeable.	
Connections to prior experiences	If a student makes a connection to a prior experience, • what preceding or following interactions, (with a curricular attribute, teacher, or student, if any) supported the student in making this connection? • what subsequent interactions (with a curricular attribute, teacher or student, if any) built upon the student's connection to the prior experience?	Example 1 (*Prepare to Investigate* rich case, second-hand investigation): Ms. Allen: Everybody thinks that the length of the legs…In what way will make a difference? Go ahead Bethany. Bethany: Because sometimes if your legs are bigger and longer, sometimes you can pedal harder than other people. Ms. Allen: Is there any…so pedaling harder. Do you agree with that Sam? Sam: Um, like a little and not a little. Ms. Allen: Say some more. Sam: Because I race my brother sometimes and his legs are longer than mine. And I defeat him some of the times and then sometimes I don't. And it's like it's kind of hard to explain. Ms. Allen: Well, keep going. You're doing a fine job. You're saying that, for you, that's evidence that the length of your legs doesn't make a difference. Because you know that the length of your legs are different and sometimes you win and sometimes you lose. Sam: It's more of the strength inside of your legs at the certain time.	Sam was supported in making connections to a prior experience by the curricular materials, which depicted a bike race scenario, by Ms. Allen, who asked students to respond to a peer's assertion, and by Bethany, whose assertion he directly responded to. Ms. Allen also built upon Sam's connection by refining his contribution using scientific terminology, which ultimately led Sam to elaborate upon his thinking.	Sam made a connection to a prior experience in response to Bethany, who provided him with a contrasting opinion. Ms. Allen also supported him by asking him to respond to Bethany's statement. She also wrapped up his statement by restating and clarifying it. This helped him state a scientific hypothesis based on his own experience. It seemed like Ms. Allen's reaction to Sam's comments either made him feel confident enough to respond more fully or helped him think about the bike race with his brother in a new way.
		Example 2 (*Engage* rich case, interplay featuring first-hand investigation): *Text excerpt occurs after Mr. Cannon has asked students who they think will win in a bike race between himself and their peer, Lena.* Denny: You would probably win [inaudible]. In a grand prix race, and it's about the weight. It's not about the [inaudible], it's about the weight. And um usually the heavier the faster.	Denny was supported in making a connection to a prior experience by the curricular materials, which posed a bike race scenario, and by Mr. Cannon who asked	Denny made a connection to the Grand Prix race because he had that prior knowledge and could connect it with the bike race in the

		Mr. Cannon: Hmm. Sienna? Sienna: I think that maybe none of you would win because if your bikes if it was too small, you'd break it, and if it was too big you wouldn't be able to reach the pedals. Mr. Cannon: Oh. OK. So just the size of the bike would be a problem for us. Any other thoughts? Thea? No? Liam? No? Naya?	students to give their predictions of who they thought would win the race. There were no subsequent interactions that built upon Denny's connection.	curriculum. He was also supported by Mr. Cannon asking him to make a prediction. But Mr. Cannon didn't follow up on his connection.
Argumentation	If a student generates a conceptual argument/claim, • what preceding or following interactions (with a curricular attribute, teacher, or student, if any) supported the student in making the conceptual claim? • what subsequent interactions (with a curricular attribute, teacher or student, if any) built upon the student's conceptual claim?	Example 1 (*Report* rich case, second-hand investigation): Ms. Allen: Alright. Quickly, we're going to sample the claims. These are called claims by the way. They're things that we think are accurate. They're statements that reflect what we think is accurate given the data that Lesley had. Lawrence, you're going to go first, please. What claim did you think Lesley could make about what happens to the speed of the cart when you add mass? Lawrence: Do you write it or what? Ms. Allen: No just say it out loud to us. Lawrence: The speed will go faster as you take away mass. Ms. Allen: Do you all agree? The speed goes faster as you take away the mass. What do you think Leonard? Leonard: I think that that's right. Ms. Allen: You agree? Leonard: Yes.	Lawrence and Leonard were supported in making conceptual claims by the curricular materials/notebook text, which provided the data that they based their claims on, and by Ms. Allen, who asked them to derive a claim based on Lesley's data. Ms. Allen and Leonard built upon Lawrence's claim, because Ms. Allen revoiced Lawrence's claim and then asked Leonard if he agreed with Lawrence.	The materials supported Lawrence in making his claim, because he made it based on Lesley's data. Ms. Allen also asked him what his claim was. Then Ms. Allen built upon Lawrence's claim because she asked Leonard if he agreed.
		Example 2 (*Prepare to Investigate* lean case, first-hand investigation): Mr. Cannon: How does changing the number of blocks change the time it takes for the cart to get to the end of the board? That's one question. Ted? Ted: Um. Uh. Because the the blocks weigh like probably 10 oz. Mr. Cannon: Uh huh. Ted: And If you have 3 blocks on there, that weighs about 30 oz. I'd say, 'cuz, if you put more on there, it's gonna be heavier so it won't go as fast because it's got more weight. Mr. Cannon: Ah okay. What about the other question? We've got one question written for the blocks. What's our other question for the model? What else could we ask?	Ted was supported in making a conceptual claim by the curricular materials, which led him to make a prediction for the results of the investigation, and by Mr. Cannon, who stated the investigative question. There were no subsequent interactions that built upon Ted's conceptual claim.	Ted was supported in making a conceptual claim by the materials, because he saw the blocks and the setup. Mr. Cannon also supported him by saying the question. But he didn't build upon Ted's claim.

APPENDIX L: ASSERTIONS TABLES PER SET OF CONTRASTIVE CASES

Engage Contrastive Case Studies - Characteristics of Rich and Lean Contrastive Cases that Led to the Relative Richness of the Learning Opportunities Provided (Teacher move (T); Student move (S); Curricular attribute (C))

Claim	Rich Case (interplay - Mr. Cannon, featuring first-hand investigation)	Lean Case (first-hand investigation - Mr. Cannon)
1.1	Teacher (T) engages students in two-tiered questioning process about the hypothetical scenario thus eliciting a wider range of student responses (S).	Teacher (T) engages students in considering one direct question about the hypothetical scenario, thus eliciting a narrower range of student responses (S).
1.2	Teacher (T) makes explicit attempts to engage specific students (S).	Teacher (T) makes general attempts to engage class (S).
1.3	Teacher (T) does not insist that students align their responses (S) with the exact features of the scenario.	
1.4	A student makes a connection to a prior experience to support his viewpoints (S); Teacher acknowledges this link (T).	
1.5	Teacher (T) probes students to give a rationale for their claim when their rationale was unclear (S).	Teacher (T) does not probe a student when rationale for her claim was unclear and stated with a disaffected stance (S).

Prepare to Investigate Contrastive Case Studies - Characteristics of Rich and Lean Contrastive Cases that Led to the Relative Richness of the Learning Opportunities Provided (Teacher move (T); Student move (S); Curricular attribute (C))

Claim	Rich Case (second–hand - Ms. Allen)	Lean Case (first–hand - Mr. Cannon)
2.1	There is no need to prepare students to engage in a first-hand investigation, thereby freeing up instructional time for other tasks (C).	There is a need to prepare students for a predetermined investigative setup while also at the same time trying to enlist help of students in co-creation of the setup. The balance between these two goals was difficult to achieve (C).
2.2	Teacher (T) facilitates engagement in literate practices in service of conceptual basis for engaging in that practice.	Teacher (T) facilitates engagement in literate practices in a procedural fashion with no discussion of conceptual basis for engagement in that practice.
2.3	Teacher (T) appropriates student ownership of ideas thus encouraging student appropriation of peer ideas (S).	Teacher (T) constrains student ownership of ideas by changing wording of student ideas (S) without student permission. disregarding student ideas (S). correcting students without explaining why they were wrong (S).
2.4	Teacher (T) collects and supports elaboration of multiple and opposing student viewpoints (S) without presuming one correct answer.	Teacher (T) sometimes collects opposing student viewpoints (S) but only supports elaboration of correct answers.
2.5	Teacher (T) collects ideas from multiple students (S) even when one student has the most to say.	Teacher (T) does not collect ideas from multiple students when one student dominates discussion (S)
2.6	Teacher (T) acknowledges and compliments student tangents (S) that pertain to conceptual arguments.	Teacher (T) gives minimal acknowledgment of student tangents (S) that pertain to conceptual arguments.
2.7	When students express confusion (S), teacher (T) responds by revoicing, often using scientific terminology, to help student elaborate.	When students express confusion or give an incorrect answer (S), teacher (T) responds by providing correct answer but does not explain why students' answers were wrong. giving "fill in the blank" questions that lead students to guess the desired answer.
2.8	Students make connections to prior experiences (S) to support their viewpoints; Teacher (T) acknowledges these links, sometimes by following them up by revoicing and helping students to elaborate.	
2.9	Teacher (T) clarifies abstract concepts by annotating information and probing students to explain their confusion (S).	T does not clarify abstract concepts (T).

Prepare to Report/Report Contrastive Case Studies - Characteristics of Rich and Lean Contrastive Cases that Led to the Relative Richness of the Learning Opportunities Provided (Teacher move (T); Student move (S); Curricular attribute (C))

Claim	Rich Case (second-hand investigation - Ms. Allen)	Lean Case (first-hand investigation - Ms. Baker)
3.1	Though the curriculum (C) has the potential to constrain student learning by not engaging them in first-hand investigation, the teacher (T) facilitates learning activities, such as illustrating the investigative setup, that serve to stand in place of first-hand investigation. the data available in the notebook text for the students to analyze (C) is reliable and has the potential to lead students to accurate conceptual understandings.	Though the curriculum (C) has the potential to benefit student learning by engaging them in first-hand investigation, time constraints arose as a result of time being used for the first-hand investigations. This forced the teacher (T) to curtail instruction, leaving the students with incomplete and uncertain conceptual understandings. unreliable student-collected data (S) force the teacher (T) to resort to providing the students with other data to analyze.
3.2	Teacher (T) appropriates student ownership of ideas conveyed in the notebook text (C) by releasing responsibility for guiding an activity to the students (S). encouraging them to state ideas in their own words (S). eliciting their thinking about topics (S) before reading about Lesley's thinking about those topics. drawing parallels between ideas expressed by scientific thinkers in the notebook text (C) and the students (S) engaging students in performing procedures that Lesley performs in the notebook text.	T (T) constrains the potential for students to appropriate ideas by performing procedures for them.
3.3	Teacher (T) facilitates engagement in literate practices in service of conceptual basis for engaging in that practice. (This process is facilitated by the fact that the data available in the notebook text (C) provide one common data corpus for all students (S) to focus on and discuss together.)	Teacher (T) facilitates engagement in literate practices in a procedural fashion with no discussion of conceptual basis for engagement in that practice. (This process partially evolves as a function of the multiple sets of student-collected data (S) – thus making it more difficult for the teacher (T) to facilitate a coherent, focused discussion.)
3.4	When students demonstrate confusion (S), teacher (T) responds by probing the student to develop a better understanding of the misconception and then acknowledging whatever is helpful about the student's contribution (S). discouraging unproductive student thinking (S) by pointing out how that line of thinking is flawed. posing prompts or questions that guide the student to think more carefully (S).	When students demonstrate confusion (S), teacher (T) responds by telling them they are wrong. asking students to try again (S) without providing support. asking another student to respond (S) to the question.
3.5	Teacher (T) helps students to make connections with each other's ideas and acknowledges student responses when they spontaneously build upon one another's contributions (S).	

APPENDIX M: ACCURATE AND COMPLETE STUDENT-POSED CONCEPTUAL CLAIMS DURING PREPARE TO REPORT/REPORT PHASE OF WEEK 1

Instructional Group	Number of Claims	Claims
1st Ms. Baker	0	
1st Mr. Cannon	1	Victor and Leo: As you add washers, cart gets faster for 1 and 2 blocks. But for 3 blocks, it didn't have the right amount and it wasn't even so it would slow down – because there was more weight on the cart than the washers could pull.
2nd Ms. Baker	2	Cory: Mass makes the cart go slower because force makes it go faster and it pays off. Todd: When you have more weight, if you pedal as fast as you can, you can probably go as fast as you could without the backpack.
2nd Ms. Allen	5	Renee: In order to tie, the heaviest person would have to pedal really, really fast. Medium weight would have to pedal less fast. And lightest person would pedal least fast. Sam: The speed goes up by one tenth of a second each time you add mass. The speed will go faster when you add force. Bethany: As the mass gets heavier, the cart gets slower. If you take away mass and add force, it gets faster. Bethany: If you were Jermaine pedaling hard, you could go same as Felicia because she was lighter. Leonard: Slight and light would be like Felicia because she's light and slender. She got for the model 1.2 tenths of a second. Moderate and medium would be Lesley. She got 1.2 tenths of a second. Strong and heavy would be Jermaine. He got 1.2 tenths of a second. So that might be the explanation why they tied the race.
Interplay Ms. Allen	2	Leah and Theresa: When you added more mass, it slowed down. (Also include inaudible statement about force-motion relationship) Leah: Says that Ms. Allen must have pedaled faster in order to tie with Theresa.
Interplay Mr. Cannon	2	Thea and Naya: For a heavy person, adding more washers makes the cart go faster. Rianna: Gravity attracts to heavier things.

APPENDIX N: ACCURATE AND COMPLETE STUDENT-POSED CONCEPTUAL CLAIMS DURING PREPARE TO REPORT/REPORT PHASE OF WEEK 2

Instructional Group	Number of Claims	Claims
1st Ms. Baker	10	Kiely: When we changed the number of blocks on the cart, the length of the spring got longer. Sid and Dion: When there are more blocks on the cart, the spring stretches out bigger. Sid and Kiely: When there are more blocks on the cart, the spring stretch is longer. Shawn: When there are more blocks on the cart, it takes more washers to make the cart move. Mia: When there are more blocks on the cart, it takes more washers to go up the board. Mia: There are more washers than there are blocks to make it go up. Shelly: You probably need at least a threshold amount to make the cart go up. Shelly and Ellie: When there are more blocks on the cart, there needs to be more washers to get the cart up the board. Shelly and Sid: When there are more blocks on the cart, the number of washers to make it move is bigger/larger. S (unclear who): Ms. Baker is bigger than Zachary so she will have more force.
1st Mr. Cannon	7	Lara and Zoe: The numbers go higher as we put more blocks on the cart, so the spring stretches more. Victor and Leo: The spring stretches 3 cm when a block is added. Levi and Ted: Each time a block is added, the washers increased by 4 (first by 4, then by 3). The number of blocks also affects the length of the spring. The stretch is first 7.9 then 5.2 then 8.7. Sandra and Linda: As we added blocks, the washers went up by 2 and then by 4. Linda: The force (represented by washers) increases as we add more blocks. Ted: Agrees with Linda that the force (represented by washers) increases as we add more blocks. Ted: The force (represented by spring) increases as we add more blocks.
2nd Ms. Baker	3	Nicholas: just like in bike race. Weight is good and also bad. It is good because it gives it more force for gravity to move it down. But it can also slow you down. Corinne: Shows that for tie to occur, heaviest person had most force and lightest person has slight pedaling. Todd: When heaviest person has least force arrow, shows that he will lose with lightest person applying greatest force coming in first.
2nd Ms. Allen	14	Leonard: Just because Tony was heavier than Lesley, it didn't make a difference to her time. Aaron: The spring gets longer as Lesley added more mass. Aaron: Every time more mass is added, you have to add more washers. Leonard: Every time more mass is added, the force had to get greater too. Bethany: There is more force when there is more mass. Sam: More force is on the heavier person Leonard: Shows with arrow magnets that Lesley would have more force and Tony would have medium force. Says that Lesley would go down faster because of aerodynamics and the force of gravity. Thalia: The bikers did different force which is why they tied even though they weigh different amounts. Leonard: Felicia would be slight pedaling – wouldn't be able to pedal as

		hard, but she is light so she can pedal easier. If all had equal pedaling force, then Felicia would win, Lesley in middle, and Jermaine would lose. Sam: Medium weight and moderate pedaling force may be better, because you're not weighing down the bike and you're not pedaling really slow. Lawrence: If the same amount of force were applied on Lesley and Tony, Lesley would win. Sam: In order for Lesley and Tony to tie, they must have each applied different amounts of force. Bethany: Tony needed to have greater force than Lesley in order for them to tie. Leonard: Agrees with Bethany.
Interplay Ms. Allen	1	Riya: In order for all skateboarders to tie, the force of gravity that is acting on each of them would be proportionate to their mass (shows using arrows).
Interplay Mr. Cannon	6	Thea: As Lesley added more blocks to the cart, she added more washers. The spring length became longer each time she added a block. Lena: Agrees with Thea's interpretation re spring. Lea: (In reaction to Lesley's claims) Even though someone was heavier, they still could have tied in the race. Rianna: Gravity would affect Tony more since he weighed more. Sienna: Gravity had to use more force to push Tony down because he was heavier. Thea: More washers resulted in gravity pulling it (spring) down further.

APPENDIX O: TRANSCRIBED SEGMENT FOR ENGAGE RICH CASE, MR. CANNON'S INTERPLAY GROUP (FEATURING FIRST-HAND INVESTIGATION)

10/20/03:
Segment 1: 3:44 – 8:44

Mr. Cannon: First off what we're going to do is we're going to try to imagine a bicycle race. OK? And it was between 2 riders. And I was one rider. And let's say Lena was the other rider on the other bike. OK? We both had the same kind bike. And you know the same tires. So the bike was the same. What do you think would happen if the two of us raced? Sienna?
Sienna: You would win.
Mr. Cannon: I would win?
Sienna: You would win because you would pedal faster and she might win because she's lighter.
Mr. Cannon: Oh. I'd win because I could pedal faster and she would win because she's lighter. Rianna?
Rianna: If you were going down a hill, she would probably win because she's lighter and um gravity pulls it's easier for gravity to pull a lighter thing down.
Mr. Cannon: Oh. I see. OK. Uh…Tom?
Tom: You would probably lose. Because gravity would have to take more weight and the gravity would use less light. And gravity might… If you were going down a tall hill
Mr. Cannon: Uh huh.
Tom: and it just went down like this, none of you would win. (shows steep hill with hand.)
Mr. Cannon: None of us would win?
Tom: If you were going down like this. (shows with hands again)
Mr. Cannon: Oh! OK. Naya?
Naya: I think there's a possibility of you winning because you would have a bigger bike because you'd need one because you're adult.
Mr. Cannon: Ah. OK.
Naya: And a bigger bike can um like it sort of makes you go slow, so you might not win.
Mr. Cannon: Ah. Ok. Lena?
Lena: I think you would win because you have more force. You can pedal faster because you have longer legs. And I think you have more force than her.
Mr. Cannon: Oh. Ok. Denny?
Denny: You would probably win [inaudible]. In a grand prix race, and it's about the weight. It's not about the [inaudible], it's about the weight. And um usually the heavier the faster.
Mr. Cannon: Hmm. Sienna?
Sienna: I think that maybe none of you would win because if your bikes if it was too small, you'd break it, and if it was too big you wouldn't be able to reach the pedals.
Mr. Cannon: Oh. OK. So just the size of the bike would be a problem for us. Any other thoughts? Thea? No? Liam? No? Naya?
Naya: You could win because you have longer legs and it would be easier for you to put more force in pedaling.

Mr. Cannon: Oh. OK? Well let's say we tied. Would that surprise you if we tied the race? No? Hmm. How do you think that could have happened? Rianna?

Rianna: Um…Well if you…um if she um if she was the lightest in that case, then um then she would be able to pedal fast. If she would be lighter then she would be able to go down quicker.

Mr. Cannon: Uh huh.

Rianna: But also um you could makeup for begin heavier by pedaling really, really fast. (Shows with hands that going down a hill)

Mr. Cannon: Oh. OK. What would happen if…if it wasn't down a hill but it was just on a straight you know on a level road? It was completely flat. Would it surprise you that we tie then?

Rianna: Well not really, because you could still pedal fast. And if she's lighter, she'd be…like…. If you're on the ground, um, I don't think that would work. So actually, I would probably be surprised.

Mr. Cannon: Yeah?

Rianna: If it was just flat ground.

Mr. Cannon: Hmm. Lena?

Lena: Normally, if two bikes are exactly the same, they should go the same the speed, 'cause if everything like the handle, wheels and the bikes and if they're like the same bike then it should go at the same speed. So no matter how much force you have or how um heavy you are – it doesn't really matter, because it depends on the bike, kind of.

Mr. Cannon: Hmm. Sienna?

Sienna: I wouldn't be surprised if you tied because like I said about the bikes you would break it and she wouldn't be able to ride a bigger bike.

Mr. Cannon: Oh. OK.

APPENDIX P: TRANSCRIBED SEGMENT FOR ENGAGE LEAN CASE, MR. CANNON'S FIRST-HAND GROUP

10/20/03:
Segments 1: 7:44-11:06

Mr. Cannon: OK. Let's imagine there's a bike race. And the bike race is between…let's see…is it Lara? It's between Lara and I. OK? Um, and we…Both Lara and I have the same kind of bike. And…you know same everything. And we tied in the race. OK? What do you think about that? Lara and I race, and we tie. Is it Victor?
Victor: I got a question.
Mr. Cannon: OK.
Victor: Is it a 16-inch bike? Is it a 20-inch bike?
Mr. Cannon: Ah. Well, whatever we have, we have the same. OK? We have the same bike. Could be 20-inch tires, 16-inch tires, 26-inch tires. Alright? I can still ride a 20-inch. If um, is it, wait a minute…I don't have your nametag.
Lara: Lara.
Mr. Cannon: Lara? Lara, do you have a 20 incher. 20-inch tires on your bike. So if we both had a bike with 20-inch tires. I could ride one of those. Anything else surprising about that? Sandra?
Sandra: Do we have to race bikes? Can we like race pet butterflies instead?
Mr. Cannon: Nope. We gotta race bikes. Sorry! (laughs) Other thoughts? Ted?
Ted: Uh were you racing down a hill or…?
Mr. Cannon: Ah. Ah. Flat.
Ted: Flat.
Mr. Cannon: Yup. On a flat surface. Ah. Yeah. Sandra?
Sandra: Well, a duh you're going to tie! Because you have the same source of energy.
Mr. Cannon: Uh huh.
Sandra: Well you go the same speed because you have the same thing.
Mr. Cannon: Uh huh. OK. Linda?
Linda: Somebody could be strong enough so it's like so you don't have to tie. Because somebody could be stronger and pushing fast.
Mr. Cannon: Ah. Hmm. So who would you predict would win between myself and Lara?
Sandra: You!
Linda: You because you're bigger.
Sandra: Bigger.
Mr. Cannon: Oh. OK. But Lara and I tied. Hmm.
Sandra: There is something wrong with that.
Mr. Cannon: Yeah. How do you think that could have happened that Lara and I tied? Linda?
Linda: You could have been pedaling slow and she could have been pedaling fast. Or you could be pedaling at same speed.
Mr. Cannon: Oh. OK. Any other ideas? Ted?

Ted: Maybe because you’re a little bit bigger you could pedal faster. Um and since she’s a little bit smaller than you she can’t pedal or she can pedal like the same speed but go um like the same you know…
Mr. Cannon: Mm hmm.
Ted: …speed as you.
Mr. Cannon: Mm hmm. Mm hmm. OK. Any other ideas? Other ideas? OK.

APPENDIX Q: TRANSCRIBED SEGMENTS FOR PREPARE TO INVESTIGATE RICH CASE, MS. ALLEN'S SECOND-HAND GROUP

10/21/03:
Segments 1-2: 12:29 - 28:22

Dialogue is in response to the following text on page 1 of notebook text.
I used materials so I had 3 different weights on the cart and 3 different amounts of force. I used a stopwatch to time how long it took for the cart to get to the end of the table. I collected data as though I were observing one biker at a time. When I let the cart go, it was stopped by the pulley, so I stopped timing when I heard the cart hit the pulley. I ran a number of trials with each amount of force and mass. If the times were about the same, then I knew I had a good measurement of the time of travel of the cart. Table 1 shows the full set of data I collected.
Ms. Allen: My question to you is this. Before we look at how Lesley has actually done her investigation, I'm thinking that you're going to be able to think of how she did that before we even read about it. So that's what I'd be interested in turning to next. And yesterday you had a terrific set of ideas about what Lesley was going to include in her notebook about this investigation. So I'd like you to be thinking about that as well. Let's look at her description. First of all, let's be sure that we understand what she's going to do here. And then let's think about…what was what do you suppose when we look at her notebook and see the page where she has her data, what do you think the information will look like? What information will she have to give us? So let's reread the description and see what should be there. Leonard?
Leonard: I think that um like she should have the weight of the person, the person, the time.
Ms. Allen: OK. So you're thinking that there's going to be information about the weight. And how is she varying the weight? What is she using as a to represent weight. Let me hear from some of our young ladies.
Bethany: Um the blocks.
Ms. Allen: She's using the blocks. So Leonard is it okay if I say that she should have the number of blocks?
Leonard: Mm hmm.
Ms. Allen: OK. Number of blocks that she's investigating with. What else? Lawrence?
Lawrence: The time.
Ms. Allen: The time. The time what? Finish that sentence. The time that
Lawrence: They got to the park.
Ms. Allen: Talk about the model. That's… you're doing a fine job with the event. Now use that same idea and apply it to the model, Lawrence. The time that what? Are we talking about traveling to a park?
Lawrence: That. Mm hmm.
Ms. Allen: Not quite. But keep going with that idea.
Lawrence: The time that the cart got at the end.

Ms. Allen: The time it took for the cart to get to the end. Excellent. What else is going to be there we hope? The time it took for the cart to get to the end. (Writing on poster paper) Please Renee.
Renee: Um. Maybe the number of washers and how big they were.
Ms. Allen: Alright. Excellent. So, the number of washers. When you say how big they get, I'm not sure I understand. Can you say some more about that?
Renee: If um if they were like really small ones like about that big, then write like how big they were and how small they were.
Ms. Allen: OK. Alright. That's an interesting point you're raising. Let me ask you this. Do you think that she should be changing the size of the washers? Leonard says yes. Aaron says no. Thalia says yes. So let's talk a little bit about this. Leonard what's your thinking?
Leonard: I think like um I think Jermaine might have to change. 'Cuz he has muscular legs but yet he has long legs. So that would be like a that would be like a minor set back. And then like Felicia she has short legs so it might take her longer to pedal. But it would be easier for her to pedal because she has short legs and she doesn't have to with big bikes go up and down the whole time.
Ms. Allen: Alright. That's interesting. Aaron you don't think that she has to change the size of the washers. What's your thinking?
Aaron: Because if you change them you have all different measurements.
Ms. Allen: OK. OK. So you're saying she better keep the size of the washer the same. Otherwise we have yet another variable. I want to get back. Let me hear from Thalia first and then Leonard I want to return to your thinking about whether the leg size. And I actually want I actually want all of you to be thinking about this issue, because it's a very interesting one. And it kind of gets us back to that issue of to what extent is this a good model. Because right now do we see any way that the leg size is represented? We don't do we? So I'm wondering why that's the case. So I'd like you to be thinking about whether you think leg length or leg size how is that going to make a difference in this particular case. But Thalia you had you had something you wanted to say first.
Thalia: Um, I think that they should add washers and take away washers first and then um because of the different weight and see what happens. And they should have 3 carts and see what happens. And um and then they should do it all the same and see what happens.
Ms. Allen: OK so you 're thinking… now Thalia when you say that they should add washers. What is the washer changing? You said that it's changing the weight? Changing the weight on what?
Thalia: The bike.
Ms. Allen: On the? On the bike?
Thalia: On the force.
Ms. Allen: On the force. So it's changing the weight on the string. And I'm thinking that we need to be really careful in our thinking about that. It's changing the weight on the string, which in turn is changing the…
S: force.
Ms. Allen: The force on the bike. So I know it's easy to think "Oh do I have to be that careful in talking about this?" But we're using weight to talk bout the mass on the bike and we're using force to talk about the role that the washer or the washers are playing of

increasing the weight on the string so we have more force. Now Leonard say a little bit more about your thinking about the size of the legs. And I'm curious to know what the rest of you have to say about that.
Leonard: Like um I'd have to say that like…The reason why she should really change the washers it's because like say if you had 3 blocks on it for Jermaine and 3 washers on the string. It would like take so much to get to the end. And if you kept three washers on. And you go to like. Say if Felicia was the lightest and she had only one block. That would make a that would make her faster and it wouldn't be a tie between Jermaine and Felicia.
Ms. Allen: Oh! You're starting to make some predictions about what her data will say. Very very interesting. Well, Let me see if there are any other issues that I think we should talk about with this paragraph before we look at those data and see whether your prediction is accurate. Renee?
Renee: Well um, when Leonard was saying that uh Felicia would um since she had long legs that it would take a little bit longer. But um I used to race around the block or at some point with my friend. And I would be taller but the bike he had bigger wheels. So if I pedaled faster um he'd win. (inaudible)
Ms. Allen: OK.
Renee: and smaller wheels.
Ms. Allen: I'm glad that Renee raised that. In this case are we worried about the size of the wheels? Why not? Because every time she investigates, she's going to use this cart. And so what's going to be true of the wheels? Are the wheels something that she's going to vary? Do you agree?
Leonard: I don't think that the wheels are going to matter. 'Cuz she's going to use the same cart over and over again.
Ms. Allen: OK.
Leonard: And the times are going to be like it would be the same if she had an accurate model of the bike race.
Ms. Allen: Ok. And Bethany?
Bethany: Um, maybe she should go back and measure the size of her friend's wheels. And maybe if one of their wheels are bigger maybe she can change the wheels when um she gets back home and do it all over again.
Ms. Allen: These are wonderful comments that you are making because they are pointing to the difference between her investigation and the bike race. You're raising some really good questions. Were they riding bikes that had the same size tires? Uh, if not, then maybe that's part of the explanation. Lesley's not thinking about that as she does this investigation. Let's me press on a little bit further with Leonard's idea? I'm curious, how many of you…Could you just show me by a show of hands? How many of you think that the length of the person's legs is something that will make a difference? So 1, 2, 3, 4, 5, 6,
S: Everybody!
Ms. Allen: 7, 8, 9. Everybody thinks that the length of the legs. In what way will make a difference? Go ahead Bethany.
Bethany: Because sometimes if your legs are bigger and longer, sometimes you can pedal harder than other people.
Ms. Allen: Is there any…so pedaling harder. Do you agree with that Sid?

Sid: Um, Like a little and not a little.
Ms. Allen: Say some more.
Sid: Because I race my brother sometimes and his legs are longer than mine. And I defeat him some of the times and then sometimes I don't. And it's like it's kind of hard to explain.
Ms. Allen: Well, keep going. You're doing a fine job. You're saying that, for you that's evidence that the length of your legs doesn't make a difference. Because you know that the length of your legs are different and sometimes you win and sometimes you lose.
Sid: It's more of the strength inside of your legs at the certain time.
Ms. Allen: What do you think of that? Leonard?
Leonard: I agree part way with Bethany. Because um… She was right about how like um how strong you can pedal. But if you have longer legs then it would it would take more of your energy out to push 'em up and down from a shorter legs. So really if you were going to race with somebody, the person who would probably win is probably a short and muscular person.
Ms. Allen: Very interesting. So you're starting to think…but do you disagree with Sid that really what matters is the strength of those legs? The force that those legs have on the pedals? What do you think Tania?
Tania: I think that sometimes if the um legs are stronger you can pedal faster.
Ms. Allen: OK. So you're agreeing with Sid that it really has to do with, whether your legs are short or tall, it has to do with how much force, how much energy, I'm hearing you use all these words. How strong those legs are. Now Leonard you've introduced something very interesting that's not part of this investigation, which is who would get tired sooner. That's a very interesting question to raise. That's not what Lesley's investigating. But let's come back and talk about that as we continue to move on in her investigation. Go ahead Lawrence. I'm sorry.
Lawrence: One time I was on a race too. And um there was two kids older than me and they had bigger tires than I did. And then they both beat me.
Ms. Allen: Do you think it was because of their tires?
Lawrence: Maybe.
Ms. Allen: Maybe so. Alright.
Lawrence: and the strength
Ms. Allen: Um, looking at her explanation, so we're agreed that she's going to have to report to us the number of blocks, the time it took, the number of washers. I'm wondering what else we should expect here? Leonard?
Leonard: Um, like… The distance of her finishing the end.
Ms. Allen: Ah. Very good. Well do we know the distance? What do we know the distance to be? You look at the model and see if you can tell us. What do we know the distance to be?
Larissa: 100 cm.
Ms. Allen: 100 cm. She's going to have to keep that the same, isn't she, for this to work. There's one other thing that I'm wondering about. She says "I ran a number of trials." And actually Tania, didn't you talk with us yesterday about trials?
Tania: No I was talking to you about um how we got to the end at the same time.
Ms. Allen: Oh, ok. Somebody in this group, maybe it was you, Bethany, said that - One of the things that scientists do is they talk about how many times the scientist did the

same investigation. (video skips briefly)That’s one of the most interesting and fun things about working with this group is that you really listen carefully to one another. And that’s just great for us as learners. So, um, what do we see that Lesley is telling us here? She says “I ran a number of trials.” So did she do the same investigation several times?
Ss: Mm hmm.
Ms. Allen: Do we know how many times?
Ss: No.
Ms. Allen: No. No, we don’t. But I’m curious, why did she have to do it a number of times?
Thalia: To make sure it was accurate. And if it was changed from the first time maybe she should remember what she did wrong and then try it again.
Ms. Allen: OK. So she may get different data, you’re suggesting. And you said she might do something wrong. What could she do that would be wrong?
Thalia: She could do maybe 200 cm other than 100.
Ms. Allen: OK. That’s one way if she changed the distance. That would lead to inaccurate data, wouldn’t it? Good point. Larissa? Leonard, I’m sorry.
Leonard: I remember with um Mrs. Novak that we had to do like um valley course thing and um I got all the times right and stuff. But I went over it a number of times to make sure it was right 'cuz like if I did it once and then if I did it two more times. And the second and the third time were the same and different from the first time.
Ms. Allen: Yes.
Leonard. Then it was it’s probably going to that time so I had to change it.
Ms. Allen: So you decided that whichever the time you got most frequently that would be the time you would choose.
Leonard: Yeah. That would be the most accurate.
Ms. Allen: Or the distance actually in the valley task. It wasn’t time - it was a matter of distance.
Leonard: Mm hmm.

APPENDIX R: TRANSCRIBED SEGMENTS FOR PREPARE TO INVESTIGATE LEAN CASE, MR. CANNON'S FIRST-HAND GROUP

October 20, 2003:
Segments 2-4 18:52 – 44:24; 0:00 – 8:50.

Mr. Cannon: I've got just one column, just the first column on the overhead there. Alright. What are some things from the actual from the actual race? Like what did the actual race involve? Sandra?
Sandra: Well you had the same um speed
Mr. Cannon: Okay.
Sandra: because…the same bike.
Mr. Cannon: The same bike. Let's write that down first. So in the race you had …the bike. So if you'd write bike there under the first. Oh you don't have pencils. I can handle that. (Passes out pencils.)
Mr. Cannon: Anything else in our race? There you go. The bike. Ted?
Ted: Flat surface.
Mr. Cannon: Flat surface. Okay (writes on overhead). Flat surface. That's FLATSURFACE. I know it it's kinda' my writing gets kinda' smushed together there on the overhead. OK. Flat surf.
S: ECE
Mr. Cannon: No. It's SURFACE. No it's an A. Let me try. Sometimes when you go in there it makes it worse. There. Is that better? We got a bike. We got a flat surface. What else. Leo?
Leo: I don't' know.
Mr. Cannon: Well, we had who?
Leo: Lara and you.
Mr. Cannon: And Mr. Cannon. Right? So. Let's just say we had persons.
S: People.
Mr. Cannon: People!
S: Persons isn't a word.
Mr. Cannon: It isn't?
S: It's a word. But it isn't proper.
Mr. Cannon: People. I need to go back to fourth grade. People. Anything else? Levi?
Levi: Same bike tires?
Mr. Cannon: Ah. OK. OK. Let's just put tires right here (writing). Tires. Anything else?
S: Handlebars
Mr. Cannon: Well, those are all parts of the bike. What were the people doing to the bike?
S: Riding.
S: Racing.
Mr. Cannon: Riding. More specifically? Levi?
Levi: Racing.
Mr. Cannon: Racing. But more specifically what did they have to do in order to race. Lara?
S: Pedaling.
Mr. Cannon: Pedaling yes! Pedaling. And that's PEDALING.

S: Can I just put pedal?
Mr. Cannon: If you want to.
S: How do you spell pedaling?
Mr. Cannon: Pedaling. PEDALING. OK. And couple other things about the race. You said we were racing. What do you line up on when you race?
Ted: starting line.
Mr. Cannon: Starting line. OK.
Sandra: Start and finish.
Mr. Cannon: I'll just abbreviate start line. And Sandra you said?
Sandra: Finish line.
Mr. Cannon: Finish line (Writing). OK.
Mr. Cannon: Now, for the next column,
S: Oh they're connects!
Mr. Cannon: Mmm hmm. Let me move some of this out of the way here. OK. Well, we're eventually we're all going to get to model. OK. Now, I've got some materials here and we need to think about what how we can use these things. This is one thing.
S: It's a (inaudible).
Mr. Cannon: This is another thing.
S: Yup.
Mr. Cannon: OK. This is going to be part of our model.
S: Did you build that?
Mr. Cannon: Uh, well some people in my group did. Alright. And we've got a couple more things here. Actually that's I don't know if you can see it real well. That's a plastic ruler.
S: It's broken.
Mr. Cannon: It is? Yeah, it's just bent. There's a pulley.
S: It looks like a piece of.
Mr. Cannon: Mm hmm. We've got some
S: washers.
Mr. Cannon: Washers.
S: Do you have a ramp?
Mr. Cannon: We do. But it's not in this room. Oh there they are. I've gotta bring one of those up there. Alright. I'll take care of it. We got this. It's just a string. Alright now.
S: We're supposed to help him (referring to Ricky who appears to need help with writing)
Mr. Cannon: What's he need?
S: He needs help writing.
Mr. Cannon: Oh. Ok. If you want to help him go ahead. Alright now. OK. Alright now. In the model of the race, we need to think about what materials we can use. So the second column here the model of the race. We're gonna start thinking about what of these materials, which of these materials will we use to model that part of the race. So let's start with the bike. What of these materials will be
S: the bike.
Mr. Cannon: The bike.
S: The wheels.

Mr. Cannon: Okay. The wheels. In this case, we'll call it a cart. So this will be a cart (writing). That's CART. OK. Oh and I gotta go get this part (goes to get ramp). The flat surface. Ahhh. The flat surface will be the board. Alright. And I'll ah…just set it right here for the time being. (writing) Alright…the board. I'm gonna get myself a table up here. (Moves table.) OK. Let me put this up like right like here. Here we go. OK. So that's our board. OK. People? What from these materials will be the people.
S: The blocks maybe.
S: The blocks.
S: The washers.
Mr. Cannon: The blocks. and where will we put the blocks.
S: On that.
Mr. Cannon: Okay. We could put the blocks on the cart. Ok. And that would. OK. Alrighty? Tires. Does the cart have tires?
Ss: Yeah.
Mr. Cannon: So that stays the same. So that's just tires.
S: What's the string?

Mr. Cannon: Hmm? Oh! The string?
Linda: I know! I know! The wheels. It makes it move the wheels which makes it go.
Ted: Maybe it has something to do with the pulley.
Mr. Cannon: Alright. Maybe it has something to do with the pulley.
Linda: Yeah put the thing in the pulley. And the pulley makes the tires…and
Mr. Cannon: OK. Ah. Well. What we're going to do is hook one end onto the cart. Alright. And then we'll put the pulley on the board like like this.
Linda: So it makes it go.
Mr. Cannon: OK. And then the pulley is just there to let the rope or the string go around the corner.
Ted: So the pulley's not really…
Mr. Cannon: And what else do we need on there to represent pedaling?
Ted: Um the string
Mr. Cannon: The string and…
Ted: and the washers.
Mr. Cannon: and the washers. So.
Ted: Do we put string and washers?
Mr. Cannon: Yup. String and washers. String and washers (writing). OK. Ricky – you okay?
S: He needs help 'cuz he won't
Ricky: (squeaky voice, inaudible)
Mr. Cannon: OK. So we got pedaling being the string and the washers. Start line?
Ted: Um the end of the board.
Mr. Cannon: Well that could be one start line. Zoe?
Zoe: the book stopper
Mr. Cannon: That's actually the other end. The book stopper is the not the start line but the
S: finish line.

Mr. Cannon: We're going to put the book stopper right here like this. OK. And then that'll be our finish line. Start line? Zoe.
Zoe: The ruler.
Mr. Cannon: Ruler. Alright. So we'll have a ruler somewhere like this. We'll decide what our start line is. OK. So start line will be ruler. And finish line is… OK. Start line is ruler. Finish line is bookend. Sorry my writing is…that's RULER.
S: Book stopper.
Mr. Cannon: Book stopper. That's fine. OK. So let's go onto the third column.
Ted: Wait. We never did anything for. Oh. OK. I didn't get.
Mr. Cannon: Problems?
Ted: I didn't get washers.
Mr. Cannon: Washers. What about 'em?
S: (Inaudible)
Mr. Cannon: Oh. Well we're gonna. I didn't put 'em on. Actually they're going to be over here at some point (shows on model).
S: To move it forward. To make it go forward!
Mr. Cannon: Right. OK. Now um. Let's see here. The next the next column. Column 3. What would affect the race outcome. In other words, would it affect the race outcome if we changed it. If we changed that thing. So starting all the way back here with the bike. OK? The bike is represented in the model by the cart. If we changed the bike, would that change the race outcome?
Ss: Yes.
Mr. Cannon: Yes, so we're just going to put a check mark by the things that would change the race outcome. OK? The flat surface. Would changing the flat surface change the race?
Ss: Yes.
Mr. Cannon: Yes. OK.
S: Inaudible.
Mr. Cannon: What's that?
S: Anything you do this would probably change (inaudible)
Mr. Cannon: OK. That's probably true. The people. Would changing the people change the race?
SS: Yes.
Mr. Cannon: Yes. The tires?
S: Mm hmm.
Mr. Cannon: Mm hmm. That'll change it. The pedaling?
S: Yeah.
Mr. Cannon: Yup. Now we gotta think about the last two. The start line and the finish line.
Ted: Yeah it would because then it would affect where it'd stop and didn't stop.
Mr. Cannon: OK.
Levi: And if you kind of shorten the distance maybe it would make the race shorter.
Mr. Cannon: Make the race shorter.
S: (inaudible) getting tired, making it shorter.
Mr. Cannon: So you think we could put check marks there? OK.
Ss: Yes.

Leo: (inaudible) the book stopper it would go right off the edge. (inaudible)
Mr. Cannon: Ahh.
Leo: It would be like driving off (inaudible)
Linda: On that one (inaudible)
Mr. Cannon: You know if. I heard last hour... I heard there was a student that said you know if we raced like from here to Alaska you know that like set the starting line and the finish line like way far away.
S: That'd matter.
Mr. Cannon: That would matter. Because I wouldn't live old enough to to ever finish that race. I mean I'd.
S: You wouldn't?
Mr. Cannon: Oh no. No no. Not on a bicycle. Hmm? Oh no.
Ted: I thought you meant like like in a car or something.
Mr. Cannon: Well in a car, I might stand a chance. But on a bicycle that race would take months and months and months. Years.
Levi: And plus you couldn't do it to Alaska because you might get stuck in the snow.
Mr. Cannon: There you go. OK. Last column. Last column. Now this is of all those things that we could change. So of all the things we can change just about anything, what do we want to change? What are we what are we actually interested in changing? Do we want to change the bike?
S: No.
Mr. Cannon: No. Alright. So what we're really looking at here is what can we change and still have a fair race. The flat surface? The board?
Ted: We could change the board.
Mr. Cannon: You could.
Ted: Because what. All you need is a flat surface.
Mr. Cannon: That's true, but in this case, we're not going to. So I'm going to put a line there saying "No we're not going to change it."
S: Why?
S: The people?
Mr. Cannon: The people.
Ted: Yeah we we shouldn't change that,
Mr. Cannon: Go ahead.
Ted: because we need the people.
Mr. Cannon: We need the people. But the people are represented by what?
Ted: Blocks.
Mr. Cannon: The blocks. And to get people of different sizes, what are we going to have to do? Change the number of…
Ted: blocks.
Mr. Cannon: Of blocks. Right? So we're gonna to have to change the number of the blocks alright in order…
Ted: But don't' want to change what we use.
Mr. Cannon: We don't change what we use. That's right. That's right. So so I'm going to put a check there. And you're right. We're not going to change the blocks themselves. But we are going to change the number of them. OK. Tires? We gonna change tires?
Ted: No. We could change tires.

Mr. Cannon: We could but we're not going to. Pedaling?
S: Uh no.
Mr. Cannon: Do we have to change how hard we pedal?
S: No. Well yeah.
Mr. Cannon: Victor?
Victor: You could, you could change the washers.
Mr. Cannon: Right, right. Yup. we need to change the pedaling to see what happens. And the start line and the finish line?
Ted: Uh. Yeah. Well, we don't need to change them. Well we could.
Mr. Cannon: We don't need to change those. That's right. Ok. So no and no. OK. So of all the things that we could change, How many things are we actually working with changing? Victor?
Victor: 2
Mr. Cannon: 2. And they are?
Victor: The blocks and the washers.
Mr. Cannon: The blocks and the washers. That's right. OK. Now. Let's go on here to some questions. 2 questions, here. First off, how does changing and you need to fill in blank. How does changing the blank affect the time it takes for the cart to get to the end of the board? So were talking about in terms of this model here. How does changing what in the model affect the time it takes for the cart to get to the end?
S: Blocks.
Mr. Cannon: Uh, raise your hand. Victor?
Victor: Blocks and the washers probably.
Mr. Cannon: OK. That's that's 2 different questions. OK. Please write down in your on your first notebook page there: How does changing…I gotta get over here…There we go. (writing question on transparency) OK I've got:
How does changing the number of blocks change the time it takes for the cart to get to the end of the board?
That's one question. Let me read that to you again. How does changing the number of blocks change the time it takes for the cart to get to the end of the board? If you need any spellings help, let me know. I know some of my letters there are kind of smushed together. How does changing the number of blocks change the time it takes for the cart to get to the end of the board? That's one question. Ted?
Ted: Um. Uh. Because the the blocks weigh like probably 10 oz.
Mr. Cannon: Uh huh.
Ted: And If you have 3 blocks on there, that weighs about 30 oz. I'd say, 'cuz, if you put more on there, it's gonna be heavier so it won't go as fast because it's got more weight.
Mr. Cannon: Ah okay. What about the other question. We've got one question written for the blocks. What's our other question for the model? What else could we ask. We've asked a question about the blocks? What else are we changing.
Ted: The string and washers.
Mr. Cannon: OK. So. How does changing the what? The number of what?
Ted: The number of string and washers
Mr. Cannon: Actually it's the washers. Because we're only going to use one string but it's the washers that we're going to change the number of. So our other question is: How does changing the number of washers change the time it takes for the cart to get to the

end of the board? (writing on board) OK. How does changing the number of washers change the time it takes for the cart to get to the end of the board? Let me put that up a little higher. Ted?

Ted: Um, because if like if you have all the blocks on there and you have 4 to 5 washers, it still might get like a minimum speed – because washers weigh a little less than the blocks. So if you add 4 or 5 washers on the hook then it will pull the string which is on the pulley which will pull the cart with all the blocks on it forward.

Mr. Cannon: Mm hmm.

Ted: So um even if the cart has lot of blocks on it, washers weigh more. And if you have like about the same amount of washers as blocks then you'll get a faster speed.

Mr. Cannon: Let me. This gets us to our next set of questions. Now these first 2 questions we've asked, they relate to the model itself. But the model is trying to to get at

Ted: bike

Mr. Cannon: the real world. Right? Yeah. The bike and the people. So we could rewrite these questions for the actual race itself? And how would we state the questions in relation to the race itself?

Ted: How does changing the number of people change the time it takes for the cart to get to the board or to the end of the race?

Mr. Cannon: Say that again louder.

Ted: How does changing the number of people change the time it takes for the cart to get to the end of the race?

Mr. Cannon: Anybody disagree with that? Everybody agree with that. Let's put it that way. Sound like a good question? Yeah. Sandra.

Sandra: No.

Mr. Cannon: That sounds like a pretty good question. Let's write that one down. So it's (writing) How does changing the people change the time it takes for the

S: Can you draw a line because (inaudible)

Mr. Cannon: Oh OK. Well yeah. My line is sort of like that. Is that better? (continues with writing question)

OK. How does changing the people change the time it takes for the cart. Let me let me try move it more like that.

How does changing the people change the time it takes for the cart to get to the end of the board?

And we've got one last question. And that is the blocks related back to the people. So we've got how does changing the blocks affect the time. Right? Affect the time it takes. What's the other question that's gonna to relate back to the original race. Ted?

Ted: How does changing the speed you're going change the time it takes for you to get to the end of race?

Mr. Cannon: OK. speed you're going. It's not exactly speed…it's …

Ted: Time. Pedaling.

Mr. Cannon: Pedaling. Right.

Ted: How fast you're pedaling.

Mr. Cannon: OK. So. The last question. And I've gotta get.

S: You can write. You can just write on this.

Mr. Cannon: Oh no. It'll get. The screen'll never clean up again. I don't know about that. Let me see if I've got some.

S: (inaudible)
Mr. Cannon: Oh yeah? Hmm. Let's see. You know what I'm going to do. I'm going to grab this other one. Wait a minute. I had another one here. Ah hah. Here, let me get you this last question here. Like that.
(writing) How does changing the pedaling affect
the time …hmm? (writes rest silently)
How does changing the pedaling affect the time it takes
S: How do you spell affects.
Mr. Cannon: Yup. AFFECTS.
Ted: Are we going to put cart? 'cuz.
Mr. Cannon: Oh that's right. That's my mistake. Let me, let me put lines through that. So what should we put instead of the cart?
Ted: The bike.
Mr. Cannon: Ah. The bike. The bike. Ted's right actually.
Ted: 'cuz (inaudible) the cart.
Mr. Cannon: That's right. We're talking about the real race. That's right. Did I goof up the last one.
Ted: No.
Mr. Cannon: No?
Ted: Yeah, you did.
Mr. Cannon: Yeah. The one before should have been the bike too not the cart, right?
S: It doesn't matter.
Mr. Cannon: Oh I don't know. It would to it would to a scientist. Takes the bike to get to the end of the race. Right?
S: (inaudible) the first two are messed up. Because it says the washers change the time it takes for the cart to get to the end of the board.
Mr. Cannon: No the first 2 are okay, because we were talking about this model right here.
S: Oh yeah.
Mr. Cannon: But the last two we are talking about the real race. Yeah. Yup. And I forgot about that.

October 22, 2003
Segment 1: 2:46-7:34
Mr. Cannon: On Monday we talked about there was going to be a race between myself and who? Was it Lara? Ok. We said that Lara on the cart set up would be represented by how many blocks? Did we ever talk about that?
S: No.
Mr. Cannon: No. OK. Let me take a step back here. Maybe I got to a different place. Did I show you the cart and all the materials?
S: Yes.
Mr. Cannon: Yes. And did we talk about how the cart was going to be set up. Oh. We did talk about what we were going to change. Right? OK. And we were going to change what?
Ted: We were going to change. Oh, we were going to change…
Mr. Cannon: Lara?
Lara: The washers and the blocks.

Mr. Cannon: The washers and the blocks. Right. And what do the…Well let's put it this way. What do the blocks represent? Levi?
Levi: The people.
Mr. Cannon: The people. Specifically, what about the people?
Levi: How many people…how many people that are that are on.
Mr. Cannon: Well, there's only one person on a bike at a time. It's not how many there are but it's…
S: The weight.
Mr. Cannon: The weight. Alright. And we said that Lara was going to be one block. And Mr. Cannon was going to be how many blocks?
S: Two
S: Three.
Sandra: Why didn't you say I'm?
Mr. Cannon: Well, I wanted to say Mr. Cannon so you'd know what my name was. So I'm going to be three blocks. Alright. Lara will be 1 block and I will be 3 blocks. Now. Um. That's the first piece of information that we can put in this table. So one person from each group using good handwriting please put in Lara and then all the way over here put Mr. Cannon. (writing on transparency as speaking). Now we said that Lara was going to be 1 block so we'll put a series of ones underneath Lara. Then we can also change the number of washers. Can't we? And we could have how many washers? Did we talk about that on Monday?
S: No.
Mr. Cannon: We have 3 washers total. We could have 1 washer, 2 washers or 3 washers. Right. So we could put a 1, a 2, or a 3. Now for Mr. Cannon, how many blocks?
S: 3, 3, 3.
Mr. Cannon: Right. 3, 3, 3. Because I'm always going to be represented by 3 blocks in the model. And I can either be pulled by 1 washer, 2 washers, or 3 washers. Now the model also allows us to do one other thing. We can put somebody in here, we'll just put a question mark there, because it could be anybody. And we could represent that person with 2 blocks. And and that person would be somebody between Lara's weight and my weight. Alright.
S: I don't have a paper.
Mr. Cannon: Well, there's only one paper for each group. (inaudible). Alright. Alright. And we can pull that person by 1, 2 or 3 washers as well. Ok. Now what that does is that sets up our data table for us. OK? And it says we're going to have a situation where we're going to set up the cart. And we're going to have 1 block on the cart and then 1 washer on the cart. Another situation, could be like over here for me, and that could be where there's 3 blocks representing me pulled by 2 washers. Now here's a test. What's that one? Ted?
Ted: Um, whoever that…
Mr. Cannon: Whoever that is.
Ted: Yeah. Pulled by 2 block, or 2 with 2 blocks pulled by 3 washers.
Mr. Cannon: Right. 2 blocks on the cart pulled by 3 washers. OK. Victor. One more. What does this one represent?
Victor: Represents 1 washer.
Mr. Cannon: 1 washer. How many blocks on the cart?

Victor: 2.
Mr. Cannon: 2 blocks on the cart.

October 23, 2003
Segment 1: 4:32 – 8:56

Mr. Cannon begins by putting up a blank transparency that will show all the data students collected for 2 blocks and 1 washer on the string. Then he proceeds to write all the data students collected for this situation, separating by different groups of students.

Mass: 2 blocks					
Force:	1 washer on string				
Group	Lara/ Zoe	Ricky	Victor/Leo	Ted/Levi	Linda/Sandra
Trial 1	1.50	2.14	1.58		
Trial 2	1.07	2.06	0.81		
Trial 3	1.36	1.44	0.78		
Trial 4	1.22	3.03	0.48		
Trial 5	1.01		0.97		

OK. Now let's look at those data. What do we notice about those numbers? Victor?
Victor: Me and Leo got like some of the lowest numbers. There's a big difference between every number almost.
Leo: Because on like our one with 3 blocks and our other one with like 3 um.
Victor: We're talking about 2 blocks, 1 washer.
Leo: Yeah but, most of 'em, some of 'em had like really small ones like one of 'em has like 28.
Victor: You don't know what we're talking about, do you?
Leo: Yeah.
Mr. Cannon: Well, we're just focusing on what's here right now. Yeah, I know, you had one that was really small. But just focusing on these numbers. Do we have any numbers that seem to be really close to other numbers? Victor?
Victor: 1.50 and 1.58.
Mr. Cannon. 1.50 and 1.58. OK. So those two seem to be pretty close. Any other ones that are same? Ted?
Ted: 1.01 and 1.07
Mr. Cannon: 1.01 and 1.07. Alright. Linda?
Linda: Um, 1.58 no 1.50 and 1.44
Mr. Cannon: 1.50 and 1.44 are pretty close. I would say so.
Linda: (inaudible)
Mr. Cannon: Sandra?
Sandra: 2.22 and 2.14
Mr. Cannon: 2. 20?
Sandra: 1.22 and
Mr. Cannon: 1. 22 and
Sandra: 1.44.
Mr. Cannon: 1.44
Sandra: No! 14
Mr. Cannon: Oh. 14.

Sandra. 2.14.
Mr. Cannon: That's 2.14. 1.22 and 1.44. Those are pretty close. Now do we have some other numbers here that are a problem? That might be a problem? Ted?
Ted: 3.03
Mr. Cannon: 3.03. Why might that number be kind of a problem?
Ted: Because it's long.
Mr. Cannon: Right. Long. If you compare that number to 1.50. How does 3.03 and 1.50 compare?
Ted: They don't compare.
Mr. Cannon: They don't compare. That's true.
Ted: but (inaudible) longer
Mr. Cannon: OK. How many 1.50s can I fit into 3.03?
Ted: two.
Mr. Cannon: 2. 1.50 and another 1.50. I'll have 3.00. That still is a littler smaller than 3.03. So this number is only half as big as that number. Hmm. What about. What. Tell me this. What's the smallest number on the data table? Sandra?
Sandra: 0.48
Mr. Cannon: 0.48. And the biggest number. Victor?
Victor: 3.03.
Mr. Cannon: 3.03. If we compare 0.48 to 3.03, how do they compare in terms of how many times bigger is the one number than the other. You need to you need to think how many times the one number would fit inside the other. Ted?
Ted: 6 or 7.
Mr. Cannon: 6 or 7? Lara, do you agree with that? Yeah? OK. Yeah. I think actually that number's pretty close to 0.50. Right. And two 0.50's one. So we have 0.5, 1, 1 and a half, 2, 2.5 and 3. So we actually have 6 of these that will fit into there.

APPENDIX S: TRANSCRIBED SEGMENTS FOR PREPARE TO REPORT/REPORT RICH CASE, MS. ALLEN'S SECOND-HAND GROUP

October 22, 2003:

Segment 1: 1:24 - 5:38 (Preparing students to illustrate a trial)

Ms. Allen: Let me suggest to you how we start today. Which is, in our notebooks each of you will choose one trial that you would like to illustrate. And we're going to use the following way to illustrate. We're going to show the table. We'll draw just a little cart. A little box with two wheels to show the cart. This shows the cart going, going, going, going, going, going, going. Coming to a stop. What you're going to choose is which trial and given the trial that you choose from the table (shows table), So these are all of our trials. You'll illustrate what the condition was when Lesley ran that particular trial. So the information that you are going to supply will include what? What are you actually going to draw in the cart and on the illustration? Everybody's thinking hard? How about my young ladies here? What are you thinking? If you are trying to illustrate what the setup looked like when Lesley was running a particular trial, what information do you need to draw on this diagram? Is your hand up Bethany? Sort of? Why don't you give it a try?

Bethany: You might need to draw the table (inaudible) and um draw just like what she did.

Ms. Allen: Can you say, what do you mean "what she did"?

Bethany: You could draw the cart moving like um place to place until it just stops. And then you don't even show the washers.

Ms. Allen: Ah. Now why would you not show the washers.

Bethany: Because if you're actually (inaudible) It wouldn't' make sense for the washers to be up (inaudible)

Ms. Allen: Oh that is such a good point. But do you notice that on our illustration the washers the string goes all the way down. OK? So that's a very smart thing to be thinking about. The washers are no longer going to be here. You're absolutely right. But here the string has dropped and so you can, in fact, draw your washers. To show how many washers, how much force. Aaron?

Aaron: The blocks. The people.

Ms. Allen: OK. So you need to show us how many blocks. And what's the final piece of information you'd want to include in the illustration? If you're telling us about a trial, what other information would we need to have? Lawrence?

Lawrence: The time.

Ms. Allen: Absolutely. The time that it took. So let's turn to folders open if you would. And on one of the lined pieces of paper there, make a choice from your table. And you're certainly welcome to look up here if this is easier for you. Decide which of these trials you want to illustrate. Quickly draw the setup and fill in the setup to illustrate what that trial looked like.

Leonard: So should we just do like the trial? Like all the times for that trial.

Ms. Allen: You're going to choose just one trial. So of all these trials, and you see that there are, well let's see we can we can actually calculate. There are five. And There are 1, 2, 3 times three so nine times five is…

S: 45

Ms. Allen: Say it again.

S: 45
Ms. Allen: 45. That's right. There are 45 possibilities. And you're just going to choose the one that you are interested in illustrating. And then we'll come on up and you'll actually use a transparency of the setup. And you'll draw in what that setup looked like for the trial you chose.

Segment 1: 13:10 – 14:49; Segment 2: 0:00 – 0:47 (Students illustrate a trial on transparency and students respond to each other's illustrations)

Ms. Allen: You can do it right on the…the cart's all made for you and so you can just put in the important variables. (Renee draws). And what about the time? And then if you could describe for us, Renee, what you're illustrating, which trial and what the conditions were.
Renee: Okay, I'll exp. Um. This was trial 1 and mass of blocks was 1 and the force was 3 washers.
Ms. Allen: OK. So when Lesley investigated with a mass of 1, a force of 3, the cart took?
Renee: 99 hundredths of a second.
Ms. Allen: OK. Do you all agree? Alright. You can look at your table and you can confirm that. Alright. Thank you for showing us how to do this. Lawrence I think that you offered to be our sec. You wanted to be last. Thalia did you say you wanted to be second? And then Leonard and then Aaron. And let's get you a fresh one? (Thalia draws) See if you can find which trial this might have been. Look at your table and before Thalia even tells us the time, what might have been. Oh go ahead, you keep that ready. What might have been the time? Go ahead Sam.
Sam: 1 minute and 1 second and 32 hundredths of a second.
Ms. Allen: That wasn't the trial? Go ahead and put your trial down your time down. And we'll then we'll know which trial you were interested in illustrating. (Thalia writes 1.27) OK. So which trial was that?
S: 2
Ms. Allen: Is that correct. Trial 2? Alrighty!

Segment 3: 0:34 – 13:45 (Discussion leading up to Tukey Procedure: Reasons for measurement variation – S ideas for choosing a representative value – Reading about Tukey and discussing similarities with student ideas) Performing the Tukey procedure comes after this transcript segment.

Ms. Allen: We said yesterday, I don't know if you remember. We had what I thought was a very interesting discussion about why it is that Lesley, even though she didn't change the mass, and she didn't change the force. And she ran that condition 5 different times, she had 5 trials, and each time she got a different number she got a different number of a different amount of time. And do you remember we talked about some of the reasons about why that might have been? Lawrence? What was one of the reasons? Do you remember? Renee had some reasons and Leonard too helped us to think about this. Do you remember what they said? Or just your own thinking. Why isn't Lesley getting the same time each time she runs a trial with the same condition?
Lawrence: (inaudible) weights
Ms. Allen: Well, now, Did she. When you say different.
Lawrence: Different weights. Or more or less blocks.
Ms. Allen: Well, but here, she has the blocks are always the same. For every one of these trials she only has how many blocks?

Lawrence: 1 block
Pardon me.
Lawrence: 1 block.
Ms. Allen: And she only has how many washers on the cart?
Lawrence: 1 washer.
Ms. Allen: And yet she's getting these different times. So what could have happened?
Lawrence: I don't know.
Ms. Allen: Do you have any ideas? OK, listen carefully and see if you can understand what Renee is going to suggest to us. And Leonard. And maybe others. It looks like lots of people have ideas this time. Go ahead Renee.
Renee: What I said yesterday was um if she had put it at the one spot and then when down there to grab onto the washers, it might have rolled. Because when sometimes when something that is circle, you put it down and it'll roll. So she needed somebody else to hold the cart in its spot. And she was way down there (inaudible)
Ms. Allen: Ok. Alright. So Lawrence does that make sense to you. What Renee is suggesting might have happened.
Lawrence: Yes.
Ms. Allen: OK. Thalia has an idea and then Leonard and Sam and Aaron.
Thalia: I think that maybe she either did it too, she didn't do it the same distance or um …that's all.
Ms. Allen: OK. So is that a similar idea to Renee's idea? Okay. Leonard.
Leonard: When I said um two reasons why she could have timed it wrong yesterday. One of the reasons is like Thalia that um, in the picture it does show like about that much of the string hanging down. And um, when she did like it a 2nd, 3rd, or 4th or 5th time she could have pulled it all the way back and that would have been a different distance. Or she could have pulled it more up.
Ms. Allen: OK.
Leonard: And then another thing is that she could have timed it wrong because it's a really hard thing to do when you're timing hundredths or tenths of a second
Ms. Allen: Ok. Lawrence?
Lawrence: I forgot.
Ms. Allen: Sam?
Sam: She might have accidentally like knocked the table so it went forward a little.
Ms. Allen: OK!
Sam: Or she might have given it a push some other time. Or somebody might have
Ms. Allen: Alright.
Sam: Like if she had a little brother.
Ms. Allen: OK!
Sam: (inaudible) Or something.
Ms. Allen: Excellent. These are all very possible reasons why even though she has the same conditions she might have gotten a different time. Did you remember Lawrence, please.
Lawrence: My name's not Larry.
Ms. Allen: Lawrence.
Lawrence: Like Sam said, she might have had a little brother. And her Little brother might have tripped and fell on the table.

Ms. Allen: OK! So hopefully she's doing this in her lab without little brothers running around. What were you going to say Leonard?
Leonard: That a reason she could have put like um um something on table, like eraser shaving, that it could have bumped on and then it would decrease the time.
Ms. Allen: OK. These are all very very reasonable ideas about why she might have gotten those differences in times. But now we need to say. Alright, well. So there is variation. How are we going to choose the number that will stand for. How are we going to decide what number will best tell us about the time it took in each one of these conditions. So I'm just curious to know how you think you would do that. Thalia do you have some ideas? Like if I said to you, choose one number, one number that tells us what happened when she had let's choose this one actually what number what time it took when she had a mass of 1 and a force of 1. How would you go about choosing the best number to represent that?
Thalia: I would make the same cart the exact same cart on the one that she
Ms. Allen: OK. I'm not talking about. Alright. I'm not talking about changing. Now I'm talking about working with the data. Actually trying to make a choice. To look at all of these numbers and say - Which one of these numbers can stand for, can tell me the time that it typically took when there was a mass of 1 and a force of 1. Looks like Leonard has an idea.
Leonard: Um Yeah. Because um there is two times that are have like 130 or in the 130s. And then there is three times in the 120s. So it's most likely gonna be a 120. And you have a 127, a 123 and a 125. And so, what's in between the 123 and the 127 is 125. So that might be the most accurate um time that it took for the cart to get to the end.
Ms. Allen: Oh, very interesting reasoning. Let's see if that works with another example. And let's see if the rest of us can use that way of thinking and see if it helps us. Uh, let's take a look at this one. So here we have a mass of 2 and a force of 2. And once again every trial we have a different amount of time. So let's use the kind of reasoning that Leonard was engaged in or some other way of thinking about this. How would you choose a number? Aaron, you wanted to talk the last time. Do you have an idea for how you would choose the time that can stand for this range of times? Anybody. Renee has an idea. Bethany how about you? Do you know what our problem is here? Let's think together about his. We're trying to. And then I'm going to introduce you to a way that. One way that scientists do it which is actually similar to some of the description that Leonard has given us. When you look at these numbers, if you were trying to choose one number, Bethany. And there is no right or wrong answer. So I don't want you to worry about his. There is no right or wrong answer. This is just your best thinking. If you were looking at these five numbers and saying, huh, I want to choose one that I think is the best way to represent the number or that tells us what the typical time was.
Bethany: It might be 1.23 and a half.
Ms. Allen: Ah that's interesting. Say what you're thinking. I think that's a very good choice.
Bethany. Because um it's just one time away from 1.24.
Ms. Allen: Absolutely.
Bethany: So I figure, if you just try to divide those into you'd get 1.23 and a half.
Ms. Allen: OK very reasonable way to think of it. Who had a different idea? Sam what were you thinking?

Sam: (inaudible)
Ms. Allen: So you didn't have a different way. Alright, well let's take a look at Lesley's notebook because she actually comes up with yet another way that it could be done. So who would like to read the paragraph that's right underneath our table? And actually Aaron you actually read for us the other day. So I'm wondering if somebody else would like to do the reading. I don't want you to be doin' all the work! How about it Taylor? Right underneath the table where we're right here.
Taylor: How far do I read?
Ms. Allen: Just right to there.
[Taylor reads aloud.
How do I look for patterns in the data? How do I deal with having multiple trials for each amount of force and mass? I talked with colleagues down the hall to get ideas. Marissa told me about a strategy by a famous researcher, Dr. Tukey. He had a simple way to determine a single value to stand for a group of numbers. With his procedure I had a way to find one number that would stand for all five trials!]
Ms. Allen: Ok. Colleagues just mean those are her co-workers, her colleagues. So she's gonna come up with. This this Dr. Tukey's gonna help her to think about that. Does that seem like a good idea – to try to simplify this by coming up with a single number? You think so Bethany? Yeah, because this is an awful lot to look at and make sense of. Let's keep reading on to see. Leonard, go ahead. What she did. Oh I'm. Go ahead
Leonard: (inaudible)
Ms. Allen: The next sentence, paragraph. Excuse me. Yes.
[Leonard reads aloud
Tukey's first step was to cross out the numbers that were likely to be the least accurate. In my case, this meant the values in the hundredths-of-a-second column. Tukey's next step was to put the values in order, so I ordered the times from fastest to slowest. Finally, Tukey said to select the value in the middle, which in my case was the third value. Figure 2 shows my use of this procedure for the set of trials from timing the cart with 1 block pulled by 1 washer.]
Ms. Allen: Alright. Let's make sure we understood what Tukey's procedure is. So if you would look at the notebook text and then we're going to try it out with another column the second column of numbers. So here we have the data from the mass of 1 and the force of one. So the first thing. And this is interesting, because - Do you remember when Leonard said it's very hard to get an accurate measure to the hundredths of a second. That's exactly what Tukey thought too. And so he said, you know what, since that's likely to be the least accurate, let's just lose it. Why is it so hard to time to a hundredth of a second. What are you doing with a stopwatch when you're timing, Do you know how to use a stopwatch? Have you ever used one? How about it Taylor? How many of you have used a stopwatch. Not sure?
Taylor: I don't really remember but I know this like (inaudible).
Ms. Allen: Alright. And do you know how it runs? How it operates. What do you have to do to start it and to stop it
Taylor: push a button.
Ms. Allen: Ah hah! Bethany, what were you going to say?
Bethany: I was going to say the same thing.

Ms. Allen: OK. You have to push a button. So you are stopping and starting by pushing that button. And it may be very difficult, in fact it is very difficult, to push it as fast as you want to when it's time to stop. So that's why it's often the case that that hundredths column is probably not the most accurate. Alright. So here you see that the first part of the procedure is to lose the hundredths.

From this point Ms. Allen *continues to review the rest of the Tukey procedure. As a group, class then performs Tukey procedure with one set of trials. Finally students perform Tukey procedure with the next set of trials independently in their notebooks.*

October 23, 2003:

In prior segment, students engaged in stating what questions they thought the investigation was testing. In this context, Renee responded to one question with a multivariable claim that accounted accurately for the mass-motion and force-motion effects.

Segment 3: 9:07-13:45 (Whole group activity: Students identify patterns in data table in order to determine the effect of mass on motion of the cart)

[Discussion is around the following table that Ms. Allen posts on transparency.]

Table 2: Summary table of the effect of changing the amount of mass and force on the motion of a cart.

Mass (# blocks)	*1*			*2*			*3*		
Force (# washers)	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (seconds)	*1.2*	*1.1*	*1.0*	*1.4*	*1.2*	*1.1*	*1.6*	*1.3*	*1.2*

Ms. Allen: So now we have some ideas, I think, about what the questions are that Lesley's investigating. And it's time now for us to think about what you think the answers are to her questions, given the data that she has. Now yesterday, we did figure out ourselves, how to choose a number that would be the number that can stand for or tell us in more sort of like a summary number. Right? And this is the summary table that Lesley has in her notebook. (Ms. Allen posts Table 2 on transparency) I'm going to give you her notebook that has her summary table. But before I do, I'm really curious to know what you think her results tell us. So if we think about the question. And I want to suggest to you that the question that you asked, and several groups got this. The question – (writing on overhead) what happens to the speed of the cart when you add what? Aaron?

Aaron: Mass

Ms. Allen: When you add mass? And what's her second question – what happens to the speed of the cart when you add?

S: Force.

Ms. Allen: Force? So I'm not going to repeat all of that, I'm just going to say – when you add force. Well, let's look at our data and see. So if we wanted to figure out what happens when you add mass, what numbers would we look at? Come on up here Aaron and point to the information that would tell us what happens as you add mass

Aaron: The cart goes faster when you add this one and it goes even faster with one more. And it goes even faster than 2 if you add 3.
Ms. Allen: Well, come here for just a second and let's check that out. So you're suggesting that we. Now remember. What are we going to have to keep the same to answer this question about what happens as you add mass? Can we be changing both the mass and the force at the same time? Oh no! Absolutely not! So, let's look at. Which one do you want to look at - the mass when you have a force of 1, 2, or 3? You choose. Sam?
Sam: 3
Ms. Allen: 3. Alright. What happens when you add mass and you have the force of 3? So the first number. What time do you get here?
Aaron: 1.0
Ms. Allen: (circles 1.0 on transparency) And then what happens the next time when you increase the mass by one and you're still using a force of 3, what time do you get? Everybody be thinking. Where did she add a mass of 2? Where does she have 2 blocks? (Aaron points to the overhead.) Alright. And what which is the which shows us where she had a force of 3. (Aaron points) OK. And so what's the time.
Aaron: 1.1
Ms. Allen: OK. (Circles 1.1 on transparency) 1.1 seconds. And now she adds yet another block to have a mass of 3. Ok. And the time was.
Aaron: 1.1,1.2 seconds.
Ms. Allen: OK. (Circles 1.2 on transparency) Everybody. Open your journals quickly and write. Thank you Aaron. Write what do you think she can say just looking at those times. As you add mass and you keep the force the same, what happens to the speed of the cart?
S: Do we write everything that you just said?
Ms. Allen: No. You just write what happens. What happens to the speed of the cart as you added mass to the cart?
Segment 4: 2:02 – 4:23 (After independently writing mass-motion claims with individual assistance from Ms. Allen, students report out their claims.)
Ms. Allen: Alright. Quickly, we're going to sample the claims. These are called claims by the way. They're things that we think are accurate. They're statements that reflect what we think is accurate given the data that Lesley had. Lawrence, you're going to go first, please. What claim did you think Lesley could make about what happens to the speed of the cart when you add mass?
Lawrence: Do you write it or what?
Ms. Allen: No just say it out loud to us.
Lawrence: The speed will go faster as you take away mass.
Ms. Allen: Do you all agree? The speed goes faster as you take away the mass. What do you think Leonard?
Leonard: I think that that's right.
Ms. Allen: You agree?
Leonard: Yes.
Ms. Allen: How did you word yours Renee and then Leonard? I had already told Renee she could go.
Renee: It went up by 1 or 2 tenths of a second.
Ms. Allen: OK. So the time of, the time went up by 1 or 2 tenths of a second as what? As Lesley?

Renee: Um. Added mass.
Ms. Allen: OK. Your turn. Leonard and then Tania?
Leonard: I wrote when you add mass, the cart went 1 tenths of a second slower.
Ms. Allen: Do you all agree? Look at all different these ways that you are finding basically saying same thing. To make the same claim but in different words. Thank you Leonard. Tania, you were going to come up next?
Tania: As it gets heavier, and it then the time gets slower.
Ms. Allen: OK. As the cart got heavier, the time got slower. Alright.

October 24, 2003:
In prior segments, students engaged in reviewing their mass-motion claims from prior day. In this context, Bethany and Sam elaborated upon their claims by making multivariable predictions that accounted for the mass-motion and force-motion effects. Students then engaged in a similar process as previous day to make force-motion claims.
Segment 1-2: 9:43-23:44 (Students read notebook text section that reviews Lesley's claims and section that discusses opposing effects of mass and force to explain tie, thus allowing more students to have exposure to multivariable prediction strategy.)

Leonard reads following text aloud:
There are two claims I feel confident to make from my data:
1. *The greater the amount of force making an object move, the faster the object goes.*
2 *The greater the mass of an object, the slower it moves in response to the same amount of force.*

Ms. Allen: Well, does Lesley agree with the claims that we made? Is she saying the same thing or she saying something different?

Leonard: She's saying pretty much the same
Ms. Allen: Pretty much the same thing, Leonard says. What do you think? Aaron.
Aaron: Same
Ms. Allen: Sam.
Sam: Same:
Ms. Allen: So everyone's thinking that Lesley may be using different language. But basically her claims are the same as our claims. Well, let's go on to see what else she says about this. Uh let's see. Aaron and Leonard have both read. Is there anyone else who would like to read? Go ahead Bethany and then Renee.
Bethany reads following text aloud:
These variables have opposite effects. So, when I'm riding my bike with my usual pedaling, and have a heavy backpack on, I will go slower. But, I can go faster if I pedal harder, and maybe I can pedal hard enough to go the same speed as I do without a heavy backpack. I think that has something to do with why we tied in the race.
Ms. Allen: So in your own words what what's Lesley saying there. Go ahead.
Bethany: Jermaine, he was pedaling um um since he was heavy he was pedaling as hard as he could to go fast. Um. So she's saying this is one of the reasons for because Jermaine. Um If that if it makes you go slower and you were traveling you were pushing

down really really hard you could go the same as like um Felicia because um she was pushing um slower but she was much lighter. And um Lesley she was kind of in the middle. So um that's why they all tied.
Ms. Allen: What do you think of Bethany's explanation. Renee?
Renee: It's what I predicted.
Ms. Allen: It's exactly what you predicted. How does that feel?
Renee: good.
Ms. Allen: Feels pretty good – huh? What do the rest of you think of Lesley's example? Thalia?
Thalia: the same
Ms. Allen: The same. Huh? This group did have a lot of interesting ideas when you started to read Lesley's notebook. Does her example of adding more weight with a backpack is that kind of a clever thing to do? What do you think of her thinking that way?
Leonard: Yeah, it's clever.
Ms. Allen: Do you want to say any more about why it's clever, Leonard?
Leonard: Because the backpack. That would be like - If Lesley was like one block, and she added a backpack to the mass it would be like 2 blocks. And and she was talking about how if she pedaled faster with her heavy backpack on - She could probably be pedaling at the same time that she was pedaling at normal without the heavy backpack.
Ms. Allen: Without the heavy backpack. Ok. That's very nice uh thinking. Let's go on to see what she does next. And Renee I think you wanted to read the next part. I know you guys are worried about getting your notebooks in. But for the moment. I'll give you plenty of time to do that. For the moment, let's go ahead and take a look at page 3 of her notebook so that we're sure we're all reading along.
Renee reads following text aloud:
I reorganized my data so that I could more easily compare the times for the cart with different amount of force and mass. And I revised the heading in the table so that the words represented the situation in the bike race.
Ms. Allen: So let's see what this new newly organized table looks like. (Passes out page of notebook) And here's the last page of Lesley's notebook. For this investigation. So again if you would all take a piece – one page. You need another one. Thank you.
Aaron: (inaudible) piece
Ms. Allen: I think we gave him one. Thank you. That's really helpful though, Aaron – that you were watching out for Lawrence. But I did pass him one when he came in. So Lawrence do you have one of a page 4 too? OK. (Puts table 3 from notebook up on transparency).
S: Inaudible
Ms. Allen: Oh. You have 2 papers. Thank you. Let's just take a moment to study Lesley's summary table. And see what you notice about the table. And if it's easier for you, you can look up here or you can look at your own copy? What do you notice Aaron?
Aaron: It got smaller.
Ms. Allen: What got smaller?
Aaron: The numbers.
Ms. Allen: Oh the
Aaron: and the table.

Ms. Allen: The table is. You mean the size of the. Are you thinking about the difference between
Aaron: this one.
Ms. Allen: Ah hah! Yes. How did she get it so small? Do you remember what procedure she used to get
Aaron: She used the number in the middle.
Ms. Allen: Exactly. Exactly. So here's her summary table that she was able to construct by just using that Tukey procedure where she just used the middle number for each of the 5 trials. Good observation. What else do you notice about this table? Anything that you would, any claims that you want to make. Or any information - If you think about the relationship between the data that are in this table and the bike race. Is there something that you notice that could help us to explain the bike race? Lawrence, what do you notice?
Lawrence: There's a light and a medium and a heavy.
Ms. Allen: Alright. So who would be the light person here?
Lawrence: Um…
Ms. Allen: Do you have
Lawrence: Lesley?
Ms. Allen: Well, I think, you know, we're not sure who. Bethany thought that maybe Felicia was the light person. Thalia?
Thalia: I think it's Felicia because um it said that Lesley was um not too heavy and she wasn't too light. But
Ms. Allen: Right, because Lesley describes Felicia as being so slender, I'm thinking maybe Felicia is the more slender. But you know – we just don't know. But let's go ahead and since most of us my sense is think that Felicia is probably the light. Uh! These are all so squishy. (Writes Felicia by light) Felicia. Which means that - Who's our medium person? Go ahead
Aaron: Lesley!
Ms. Allen: Lesley (writes Lesley by medium). And we're all agreed that Jermaine (writes Jermaine by heavy) was our
Ss: heavy.
Ms. Allen: heavy biker. Exactly.
S: It's with a J.
Ms. Allen: Oop. It's with a J? Thank you. What else do you notice? So that was a helpful observation. That each one of these columns stands for a different person. Now look at their time data and see if there's something else that you observe? Sam, do you see anything?
Sam: Well, I didn't really get what you said the first thing.
Ms. Allen: OK. What I suggested is that we look carefully at the data that are reported - the number of seconds. Now of course, one thing I need to say is. Do these data really stand for the number the time that it took for the bikers to race?
Ss: No.
Ms. Allen: No, that's ridiculous. Right? You couldn't have a bike race and get anywhere in 1.2 seconds. So remember. This is the model of the bike race that we're talking about. So Sam, if we look at the data for the model of the investigation, is there anything interesting that you notice? Any patterns? A scientist would be interested in looking at

the data and saying – Let me see if I see any patterns that can help me to understand about

Sam: Yeah, on the light and slight the medium and heavy, it goes up 2 on each one. And the moderin moderate it goes up by one each time.

Ms. Allen: OK.

Sam: And then the strong it goes up by one tenth of a second.

Ms. Allen: Alright. That's a very important observation that you're seeing that there is a a relationship between adding mass and the speed. But that the relationship's a little bit different, isn't it? That there are point 2 tenths of a second difference between the masses for the uh slight amount of force and only one tenth of a difference in the time for the moderate and strong. Good lookin'! Renee?

Renee: Well, I notice that um if you go slanted, that it goes um 1.2 tenths of a second all the way down.

Ms. Allen: Does anyone else know what Renee is talking about? Come on up here Leonard and show here what Renee means what you think Renee means.

Leonard: I don't know exactly what she means because I didn't really hear her that much.

Ms. Allen: OK. Maybe Renee you could say it again? Because it's really important that we listen to one another.

Renee: Well, um right slanted down it has 1.2 tenths of a second. So each of them made

Leonard: Like so light and slight is 1-2. Moderate and medium is 1.2 tenths of a second. And strong is heavy is 1.2 tenths of a second.

Renee: Yeah. Each one. Well each, at least one time they made 1.2.

Ms. Allen: Do you want to circle those times? Leonard is that what you were going to observe?

Leonard: Yeah.

Ms. Allen: Bethany?

Bethany: I noticed something else about. If you look at it the other way and it goes sideways, it um goes up by um 2 seconds.

Ms. Allen: Maybe you need to come up and point. I'm not quite sure I. Oh you're saying. Oh, I see. Does that? So what would that be examining? What would that be telling us about? When we look at these patterns, we want to try to understand. Hmm. Are these meaningful patterns? Do they tell us something? So what's the relevance of. Go ahead.

Leonard: Well, like what Renee said, is that like slight and light would be like Felicia because she's light and slender. So and then she got like for the model she got 1.2 tenths of a second. And like moderate and medium would be like Lesley. She got 1.2 tenths of a second. And strong and heavy would be Jermaine. He got 1.2 tenths of a second. So that might be the explanation why they tied the race.

Ms. Allen: Bethany, is that similar to what you were saying? Not when you were making this observation. But very earlier, much earlier when you were giving your explanation of how the 3 of them tied. If I'm not mistaken, I think you had the same explanation.

Bethany: Yup.

Ms. Allen: Mm hmm!

Renee: And that might be the one that um she would choose for the. Like there's other ones. But that would be the one she would pick that would be the one that would tie.

Ms. Allen: OK.

APPENDIX T: TRANSCRIBED SEGMENTS FOR PREPARE TO REPORT/REPORT LEAN CASE, MS. BAKER'S FIRST-HAND GROUP

October 24, 2003:
Segment 1: 2:05 – 11:10 (Ms. Baker hands back student data with medians circled and instructs them to write a summary table and write claims)
Ms. Baker has posted overhead of Shelly and Ellie's data on table, who collected more data than anyone else and has circled some numbers, shown below bolded.

		Ellie			*Kurt*			*Ms. Baker*		
	# blocks	*1*	*1*	*1*	*2*	*2*	*2*	*3*	*3*	*3*
	# washers	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (sec)	*1*	***1.11***	***0.84***	***0.62***	*1.11*	*0.76*	*1.20*	*2.2*	***1.24***	*0.64*
	2	*1.23*	*0.44*	*0.73*	*1.38*	*0.83*	*1.22*	***1.28***	*0.84*	*2.57*
	3	*0.84*	*0.47*	*0.42*	*2.6*	***0.73***	*0.53*	*2.28*	*1.68*	*0.86*
	4	*0.78*	*1.48*	*0.46*	***1.34***	*0.71*	*0.69*	*0.31*	*1.32*	*0.73*
	5	*1.28*	*1.04*	*0.73*	*1.17*	*0.71*	***0.69***	*1.06*	*0.82*	***0.77***

Summary table

Mass (# blocks)	*1*			*2*			*3*		
Force (# washers)	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (seconds)	*1.11*	*0.84*	*0.62*						

Ms. Baker: So the question is, how did I know which one to circle. Is that distracting everybody, Mira? OK. In each of these cases, we have 5 trials. And so I looked at the numbers, and I said which is the middle number. Which is the middle number? So here, the lowest number is 0.78. And then the next number after that is which one? Sid, Dion, get your eyes up here. The lowest time is 0.78. Which time is next? Who can help? Kiely?
Kiely: 0.84.
Ms. Baker: 0.84 is next. What time is next highest? Mira?
Mira: 84.
Ms. Baker: That's what she just said is next. That's second. This is the lowest. Then this is the next high. Someone besides Kiely? Sid and Dion? Um, you're going to have to do this with your own data. So I need to know if you can tell which numbers are circled and why. So Sid what's your thinking?
Sid: Um, 82.
Ms. Baker: Is the problem that you can't see it? (adjusts overhead)
Sid: Um, 64
Ms. Baker: So this is the lowest, and then that's next. What's after that?
S: (Inaudible. Seems to be clarifying what a number is).
Ms. Baker: Yeah. That's 1.23. Kiely did you know which one was next?
Kiely: 1.11.

Ms. Baker: This is the next one. So that's the third time and that's the one I circled. Let's look at the next one. Which here is the lowest time? The lowest number for the time? Dion?
Dion: 1.48.
Ms. Baker: That's the highest time. Which is the lowest. Mira?
Mira: 0. 1.04
Ms. Baker: Nope. See how there's several zeroes. So those aren't low. Those are higher. Mira?
Mira: 0.47.
Ms. Baker: Well, I think this is 0.44. So that's actually low.
Mira: Oh yeah. 44.
Ms. Baker: But which is the next one Mira?
Mira: 0.47.
Ms. Baker: Exactly. And then where's the third time. Kiely?
Kiely: 0. 84
Ms. Baker: Again, the third time. That's the one I circled. Let's try and see if it works one more time. What's the lowest time here? Kurt, I'm sure you know this one. Which is the lowest time in this column?
Kurt: Um, 0.73.
Ms. Baker: Nope. Do you know Ellie?
Ellie: Um, 1.42.
Ms. Baker: Yeah. 0.42 is the lowest.
Ellie: Yeah. 0.42
Ms. Baker: What's next? What's next highest. Ellie, you tell us again.
Ellie:1.46.
Ms. Baker: It's zero.
Ellie: I mean 0.46
Ms. Baker: 0.46. So Kurt can you tell what's next? That's the lowest. That's the next low.
Kurt: 0.73
Ms. Baker: Nope. Not yet. Mira?
Mira: Oh, never mind.
Kurt: 0.70
Ms. Baker: Nope, try again Kurt. Mira, can you help him out?
Mira: 62.
Ms. Baker: Yes. Again, the third number is the one I circled.
So when you get your data, I actually have already done this for you , but you need to double check. Because I couldn't always. I wasn't always sure that I that I read your writing correctly. So the first thing you need to do is to double check. And then you're going to get this summary table. And so in each case. Here we have 1 block. 1 block, 1 washer. 1 block, 1 washer. And I write the time 1.11. And 1 block, 2 washers, 1 block, 2 washers. I write the circled time, 0.84. 1 block, 3 washers. 1 block, 3 washers. And I write the circled time, 0.62. So this is what you are going to create. And from this table you're going to have to figure out what you can claim about the world. You've now run this cart. You've been changing the blocks. You've been changing the washers. So you've been changing the mass. And you've been changing the force. So what's what does the world work like? The more mass we have, what happens? The more force we

have, what happens? You have to see what your data say. And you're going to have to write claims. So that's the first step.

And what I have done for you is I didn't circle this on your actual data. So I handed back in your folders you have your actual data from the last two days. And in some cases, I actually copied on one sheet, your data from two days. So I have for example um for Mia and Kiely, they did the lightest biker on one day and they did that was the first day and then they did the heaviest biker yesterday. And I put both of those sheets together. I copied it on one sheet to make it easier for you. OK? But in other cases, like Kurt and Mira your group. Oh no, let me take Sid and Dion. I copied yours a little differently. There's a top and a bottom. Because because you copied some of or you redid some of the trials. So you have one days' data on the top and another day's data on the bottom. And you have to decide which is your best data to work from. Because you took you collected the same data again. And I don't know if you want to use all that data or if you feel that the data on one day is

Dion: Can we do both or?

Ms. Baker: You can. If you think that's all really good data. But I know some groups like I know Kurt your group made a little bit of a different decision yesterday when you were timing. So you similarly have two day's um worth of data. And you decide, Mira, you and Kurt have to decide which data you want to use. And when you are ready to write your claim…Hi Mia good to have you here. (Puts up overhead transparency of "Making a scientific claim.")

S: Is Shawn coming?

Ms. Baker: Can you get in. Sorry. This is the next step. This is what scientists are trying to get to. They want to make a claim about how the world works.

S: I'll be her partner since…(Inaudible discussion about who should be someone's partner because someone is missing)

Ms. Baker: So each group on a piece of paper, you're going to write the scientific claim you can make from your data. You're going to have to figure out what to write. And you need to write pretty large, because. When everybody has written their claims, group by group, you're going to come up and here and you're going to tell the rest of us what your claim is. And you're going to show us the data that led you to make that claim. So this is what scientists do. They present to other scientists and tell them what they found and and what they think is true about the world. And how they found that out. So do you understand what you're going to do? That each group is going to come up here to the board?

S: Well, it's already (Inaudible)

Ms. Baker: What's that?

S: (Inaudible)

Ms. Baker: Do you guys understand? You're going to come up. You're going to have to write your claim and and you're going to come up. You're going to have to explain what your thinking is and why you concluded that. And Kurt, and Shawn and Mira for your group. And Kiely and Mia for your group. You're going got have to make this little presentation. We're all going to listen to it and we're going to ask questions. Because we may not understand what you wrote. Or we may not understand your data. So you're going got have make those decisions. So I'm going to keep this up here in case you need that to refer to when you're making your claim.

Segments 3-4:6:40-14:48; 0:00 – 1:42 (2 student groups report out their claims)
Ms. Baker: Alright, Mia and Kiely are going to report first. And here's how this is going to work. what's really important is whether or not you understand what they are claiming. So if you have any questions, you're going to ask them. If you're not sure what they're saying is about how the world works, you need to ask them. And then secondly, when they show, when they tell you their data, you need to ask questions if you're not sure if their data agree with the claims that they're making. So. And I'm going to have this side of the room, Kurt and Mira and Shawn. In particular, we're going to look to you if there are any questions about the claims they are making. And this side of the room, I'm going to specifically look to you guys to ask questions if you don't think their data make sense. If you don't think they can make a claim from their data. So you guys go ahead and start.
Kiely: The more washers there are on a string
Mia: The faster the cart goes.
Ms. Baker: Ok. Stop right there. Any questions from the claims people. Do you have any questions about what they're claiming? And anybody can ask that question. (Inaudible)
Dion: (inaudible)
Ms. Baker: What's that? I don't think anyone can hear what he said.
Mia: He said he needs us to have more sentence.
Ms. Baker: Do you guys have a response to that?
Mia: Uh…No!
Kiely: That's all we could think of!
Mia: Yeah!
Ms. Baker: You wanted them to write something more, Dion? Is that what you…
Dion: Yeah, it's kind of short. There's only (inaudible).
Ms. Baker: Well actually scientists like sentences like that. They like to be very, it's called succinct. So if they can say it in a simple way, in a short way, that's what they prefer! That's a good thing. OK, call on the next hand. I think you've got another hand, Mia and Kiely.
Ellie: Well, mine is kind of like his. But then again. It was short… um, it's good. I like it. I like it.
Ms. Baker: So you don't have a question.
Ellie: No.
Ms. Baker: OK. So tell us your data. Kiely, and Mia, tell us your data.
Mia: Um, 1, 1.
Kiely: This is for one block.
Mia 1.32.
Kiely: And then for 1 block and 2 washers.
Mia: 0.93
Kiely: And then 1 block and 3 washers.
Mia: .65
Kiely: And then 3 blocks and 1 washer.
Mia: Um, 1.74
Kiely: And then for 3 blocks and 2 washers.
Mia: 1.17
Kiely: 3 blocks and 3 washers 0.9.

Ms. Baker: Now I don’t know about you but I can’t see their data and I can’t follow those times. So what I’m going to do is write right them up here. If you guys will slide down just a little bit. So you started out and you said you had one block. Is that correct?

Mia: Yeah.

Ms. Baker: And you had 1, 2, and 3 washers?

Mia and Kiely: Yeah.

Ms. Baker: And what was the time for one washer?

Kiely and Mia: 1.32

Ms. Baker: And for 2 washers.

Kiely: 1.

Mia: No, not – 0.93

Ms. Baker: And for 3 washers.

Kiely and Mia: 0.65

Ms. Baker:
[Writes on board :
1 block
1 2 3
1.32 0.93 0.65]

Ms. Baker: OK. So now we can ask you guys, do you agree that heir data support their claim. Do you agree that their data supports their claim? Make sure we can see your claim. Do you agree that their data supports their claim?

Ellie: What was the statement again.

Mia and Kiely: The more washers there are on the string the faster the cart goes.

Ellie: Thank you.

Ms. Baker: So how many people agree that their data support their claim? Raise your hand if you think you agree. You don’t agree? Are you sure? Are you sure you agree. Okay, it looks like people agree with you so go ahead and post yours up there. Mira and Shawn and Kurt get to go next. You don’t want to go? OK. Well, I’ll sit back here with you and we’ll just help out. So we’re going to help from afar. So Kurt and Mira, go up there. Mia, you need to sit down. The next group is going. They were quiet for you so you need to be quiet for them.

So this time we’re going to have Kiely and Mia, you get to be the claims people. So you’re we’re going to look to you if we don’t understand their claim. And you guys back here again are going to be the evidence people to see if their data are in agreement. OK. So go ahead group.

Mira: the more we add blocks on to.

Kurt: The cart goes faster.

Ms. Baker: Any questions about the claim?

Dion: Did they say blocks? Oh, if you put more blocks on it, how many washers do you have?

Ms. Baker: Shawn can you help them with the question? What does your data say?

S: 0.

Ms. Baker: No that’s not what he asked. You gotta answer his question.

Dion: You guys shoulda wrote the washers.

Ms. Baker: Can you answer his question?

S: (Inaudible)

Ms. Baker: No not necessarily. You don't have to agree with him. But he asked a question. Did you hear what his question was? Kurt can you answer the question. Dion back there has now forgotten what his question was. I thought that the question was. You said about blocks, but you didn't say anything about washers. And that's a really important question.
Dion: Yeah, because if you had the blocks, how's your car gonna go with no washers.
Ms. Baker: So that's one problem. But your data tell you how many washers. What does that table say?
S: One block. (inaudible)
Ms. Baker: That's about the blocks. But Dion's asking about the washers.
S: (Inaudible)
Dion: I don't get it.
Ms. Baker: They haven't really answered your question. Ellie thinks she can help. Can you go up to their data and help, Ellie?
Ellie: So I think what Dion is trying to ask is um, the washers. And washers how is the cart gonna move. And what you said. Well, for the first block and the first washers, they had they have like. They had 89. They had um 83 seconds. So that was 1 that was just 1 washer. And that can make it move in that time.
Dion: But it doesn't say washers on it.
Ms. Baker: Well, it's okay that they didn't say washers. Because there's something that was true about which times they compared to make their statement. Do you know which times you compared, Mira and Kurt or Shawn. Which times you compared. There were just 3 times that you compared. And you have 6 times written on your sheet. Or 5 times. You have 5 times written on your sheet, but there were just 3 times that you compared. What was true for those 3 times? You changed the blocks, but what was true about the washers?
S: Um, I don't know.
Ms. Baker: Oh gosh. Well, it's a bit of a problem for you to present your claim if you can't tell us. Oh look at Shawn is helping. Could you. Shawn, I'm not sure they can tell what you meant.
Shawn: There, there, there.
Ms. Baker: Did you see, Mira?
Mira: Yeah
Ms. Baker: And what was the number of washers at every time that he pointed to.
Mira: 1.54
Ms. Baker: No, what were the number of washers. Not the time.
Mira: 3 and 3 and 3.
Ms. Baker: So what's the answer to Dion's question.
S: 3, 3, and 3.

October 29, 2003

Segments 1-2:9:47-14:50; 0:00 – 9:05 (Ms. Baker continues report phase from previous week by surveying students about their mass-motion claims. Plans to use student data to support a whole class data analysis but finds insufficient data that do not support accurate conceptual understandings. Resorts to using data from

notebook text to engage students in considering mass-motion claims. Never gets to force-motion claims or to multivariable prediction.)

[Ms. Baker refers to below poster paper as she speaks:
Moving across a table
How does changing the number of blocks (weight of a person) affect the time it takes to get to the finish line?
How does changing the number of washers (force) affect the time it takes to get to the finish line.]

Ms. Baker: So I want to know what everyone thinks the answer is to this first question. How does changing the number of blocks affect the time it takes to get to the finish line? And maybe we want to add it takes the cart to get to the finish line? How would you answer the question How does changing the number of blocks affect the time it takes to get to the finish line. So how many blocks did we work with Kurt?

Kurt: 1, 2, or 3.

Ms. Baker: 1, 2 or 3 blocks. Don't give your answer yet. Because I want to ask everybody. If I put more blocks on the cart, what happens it takes to get to the end. And you're either gonna think it stays the same, it gets faster or it gets slower. Stays the same, it gets faster or it gets slower. I'm going to come around and have everybody whisper. What do you think is going to happen. (Ms. Baker circulates and collects whisper answers from all students)

Ms. Baker: Well, I can tell you that about half of you think it gets faster and half of you think it gets slower. I'm not surprised about that because we didn't get to do the reporting. So we need to look at some of our data in order to tell the answers to that. So why can we look at these.

Ms. Baker posts transparency with following data.

Modeling Ellie in bike race, strongest pedaling

	Mass	1 block			
	Force	3 washers			
	Group	Kiely & Mia	Sid & Dion	Shawn, Mira & Kurt	Ellie & Shelly
Time (seconds)	Trial 1	0.58	**0.97**	**1.57**	
	Trial 2	0.62	0.87	1.73	
	Trial 3	0.80	2.51	1.64	
	Trial 4	0.65		1.21	
	Trial 5	0.65		1.25	

Modeling Kurt in bike race, strongest pedaling

	Mass	2 blocks			
	Force	3 washers			
	Group	Kiely & Mia	Sid & Dion	Shawn, Mira & Kurt	Ellie & Shelly
Time (seconds)	Trial 1		**0.95**	1.42	1.20
	Trial 2		0.81	0.68	1.22
	Trial 3		2.51	**1.38**	0.53
	Trial 4				0.69
	Trial 5				

Dion: It's kind of blurry.
Ms. Baker: Ooh.
S: Can you move the cart out toward this way.
Ms. Baker: Toward you? Can you read how many washers in each case. Who can read how many washers.
Ellie: 3 washers. 3 washers.
S: If you can turn out the light.
Shawn: 3 washers. 3 washers.
Ms. Baker: I know it's hard to see. And we have 2 groups. WE have Shawn's group and Sid's group. And remember how I circled one of the numbers for you. Which in this case would be this number and in this case would be this number. (Circles medians for Sid and Dion's data and for Shawn's data). Unfortunately. (long pause) I have to think about what to do here. (long pause) What I'm going to do. (long pause). [As Ms. Baker figures out what to do, students start playing and making shadows. On transparency.] Unfortunately I didn't bring back your posters and the data that we have there. Um, I just didn't think that we had enough data. Kiely? Are you going to tell us the answer? What's that?
[Posts new transparency that has table 2 from notebook text (even though these students have not used the notebook)]
What affect does changing the amount of force have on the motion of a cart?
Table 2: Summary table of the effect of changing the amount of mass and force on the motion of a cart.

Mass (# blocks)	*1*			*2*			*3*		
Force (# washers)	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Time (seconds)	*1.2*	*1.1*	*1.0*	*1.4*	*1.2*	*1.1*	*1.6*	*1.3*	*1.2*

Kiely: I'm stretching.
Ms. Baker: Oh you're stretching. OK. In order to compare how changing the mass affects the cart, we have to keep the number of washers the same. So here we have a mass of 1. 1 block and 1 washer. Here we have 2 blocks and 1 washer. And here we have 3 blocks and 1 washer. As we increase the number of blocks, what happens to the time? Does it get. Does it stay the same? Does it get higher or does it get lower? What do you see right there? Mira what do you see? I saw your hand right away.
Mira: It gets lower.
S: No it gets higher.
Ms. Baker: Which are you saying? Because I want to ask how many people agree. Does it get larger or smaller the time the amount of time.
Mira: Uh. Lower.
Ms. Baker: OK. How many people agree with Mira that the amount of time gets lower? So what do you think (inaudible) instead Shelly? Shawn. That microphone is very sensitive. So we can even hear when you move your folder. So if you could just try to be. Do we need to move you to a different table, Shawn (inaudible) microphone. Would that help?

Shawn: No. Something's bothering me.
Ms. Baker: What did you say, Shawn?
Shawn: Something's bothering me.
Ms. Baker: What's bothering you Shawn? Is that table bothering you?
Shawn: No. My brother got in trouble.
Ms. Baker: Oh OK.
S: He got suspended.
Ms. Baker: Oh. That's hard. OK. Well, we'll let you kind of just ah try to let you relax about that. Shelly, um what did you think? So people didn't agree with Mira, it didn't seem.
S: I did. I said it was getting slower.
Ms. Baker: She said it was getting lower.
S: Oh, I said it was slower.
Ms. Baker: So…Because for me, these numbers get higher. Would you agree with that Mira or no? That the numbers get higher.
Mira: See It gets higher and then it gets lower. Cause it's 3 then it gets to go to 2. 3, 2.
Ms. Baker: Are you just looking at these numbers?
Mira: Yeah.
Ms. Baker: Cause I see 1.2, 1.4, 1.6. Are those getting bigger or smaller?
Mira: Bigger.
Ms. Baker: They're getting bigger.
Mira: 13 and 12. See the 13 and 12.
Ms. Baker: I know, but we're not looking at those numbers. We're just comparing these. Because we have to keep the amount of force the same each time in order to compare them.
Mira: Oh. It's getting higher.
Ms. Baker: Yeah. And so Shelly was telling us, what does it mean when these numbers bet higher. What does that mean about the speed of the cart?
Shelly: The cart gets slower.
Ms. Baker: Now was that what you whispered to me?
Shelly: Yes. No.
Ms. Baker: You whispered to me that you thought it kind of. Well actually you said, it kind of was about the same.
Shelly: Yeah.
Ms. Baker: what did you whisper to me, Sid, you thought happened with the cart?
Sid: Faster.
Ms. Baker: Is that what these numbers show.
Sid: No.
Ms. Baker: No. So your data didn't show that it got faster. What are you thinking there Shelly?
Shelly: Well I didn't know if you meant like in one box like the number of (inaudible). I thought you meant just like in one box.
Ms. Baker: Well, let's check and see if it just holds up. 'Cause maybe it doesn't hold up. Right now we compared with one washer. What do you think? Do you think it's gonna bet the same if we 2 washers on. Here's one block with 2 washers. Here's two blocks

with 2 washers. Here's 3 blocks with 2 washers. Now the times are 1.1, 1.2, 1.3. So does the same thing happen or does something different happen?
[students call aloud many answers.]
Ms. Baker: Tell us how it's different Sid.
Sid: Because look at 1, 2, 3.
Ms. Baker: So the numbers are different. Yes. The numbers are different. Instead of increasing by two tenths each time, it increases by one tenth. But why are you guys saying it's the same thing?
Shelly: Because it's getting slower still.
Ms. Baker: It's still getting slower. The numbers are still getting higher. Do you think it will be the same if we go to 3 blocks or do you think it will be different? I'm sorry yes, 3 washers? If we go to 3 washers. So here's 1 block, 3 washers. Here 2 block, 3 washers. 3 blocks, 3 washers. Now my times are 1.0, 1.1, 1.2. Is it the same or is it something different?
[choral answer: Same]
Ms. Baker: How is it the same, Kiely?
Kiely: The numbers are still getting higher.
Ms. Baker: So, what should I write what should I write here? How does changing the number of blocks. More blocks…More more blocks makes the cart go (writing on poster paper) what? How many people think it's slower? How many people think it's faster?
Shelly: Wait. What do you mean?
Ms. Baker: Who said what do I mean? Because that's an important question. Because that's a very important question. Shelly said that. Go ahead Shelly. Can you? What do you mean? Shelly, can you ask me a different question?
Shelly: (inaudible) what we were talking about up there.
Ms. Baker: If we had more blocks on the cart makes the cart go…
Shelly: (inaudible)
Ms. Baker: You think slower?
Shelly: (nods in agreement)
Ms. Baker: How many people think slower? Could you raise your hands again and I'll count. How many people think it makes it go slower? Wait. I'm not seeing everybody's hands. Kurt is one. Shawn is your hand up or not? I can't tell. It's not up. Mira is your hand up or not? It's not up. Dion's hand is up. 1, 2, 3, 4, Kiely how about you? Sid is up. I'm sorry. 1, 2, 3, 4,5 Kiely, are you agreeing that it's slower or no? And Mia how about you? You're agreeing it's slower. So 7 people. And how many people think faster? Shawn and Mira. Now what a scientist would do. When a scientist sees a pattern like this. A scientist would say - This is telling me it takes longer each time and the cart goes slower. So a scientist would conclude that it goes slower from this data. But we didn't have a chance to do all of that with our own data. And so it's really important. This week we're going to work with materials again. You're going to have a chance to collect your own data again. And hopefully you'll be able to tell from your own data. Because right now we're looking at um not everybody's individual data.

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