CHAPTER 3
MRS. MACLEAN’S CLASS ENGAGED IN “A VERY SCIENCE-LIKE KIND OF THINKING”

Since the 1960s, the expectation, as suggested by curricular materials and - more recently - by national standards, is that science teaching and learning in the U.S. will be “inquiry based.” Schwab (1964) maintained that inquiry has its origin in disciplinary conceptual structures, which determine: “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 interpretation in the light of the conception which initiated the inquiry” (p. 9). Consistent with a Kuhnian perspective, Schwab cautioned that conceptual structures of any discipline are incomplete, relatively ephemeral, and conceivably in competition with one another. Hence, in addition to imparting to students the particular structures underlying major bodies of received knowledge within the disciplines, Schwab (1964) urged that instruction must also address the manner and extent to which each discipline verifies its knowledge: “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, determine the pathway by which the discipline moves from its raw data to its conclusions (p. 11).”

Schwab was particularly critical of extant curricular attempts to impart this kind of knowledge, which he referred to as knowledge of the syntactical structure of the discipline. His complaint was that this knowledge was too often conveyed in terms of vague and vapid “methods” applied in algorithmic ways in search of conclusions.
Almost four decades have passed since Schwab’s critique, and even a cursory review of the science education literature suggests that the enthusiasm for inquiry-based science instruction has continued unabated. However, it would also appear that educators are still challenged relative to teaching the syntactical structures of the discipline of science in the service of advancing the conceptual structures. For example, in a national survey of teachers of science (Weiss, Banilower, McMahon, & Smith, 2001), half of the elementary school teachers surveyed reported engaging students in scientific investigations at least once a week, and yet only 37% indicated a heavy emphasis on learning scientific inquiry skills, and only 8% emphasized learning to evaluate arguments based on scientific evidence. Observational research suggests these statistics are accurate. Vekiri, Baxter, & Pintrich (1998), in their investigations of fifth-grade science instruction in a district that engaged in substantial professional development over several years to prepare elementary school teachers to teach science via investigative activity, reported few instances in which students were using inquiry processes, such as observation or documentation, in a manner that would engage them in the enterprise of science (e.g., examining the relationships among observations for the purpose of identifying patterns in the data, considering how data support or refute knowledge claims). Instead, they observed students experiencing the processes as ends in themselves. Similar findings have been reported by Newton, Driver, & Osborne (1999) in their study of 34 elementary classrooms.

Are these findings the result of teachers not being properly prepared to teach via inquiry, considering its challenges? A recent review by Metz (in press) of widely-used elementary science curricula (Full Options Science System, Science and Technology for Children) suggests a different problem. She observed that, while important strides have been made, the goal structures represented in these curricula are frequently “flat and impoverished” (p. 9); featuring a small number of scientific reasoning processes, with primacy placed on the development of discrete skills, which - accrued over time - would
lead to students engaging in controlled experimentation by the sixth grade. If curriculum materials designed to support teachers in engaging students in scientific investigation have such lean goals, how can we expect teachers to engage their students differently? Why are the goals so lean?

There have been several excellent scholarly reviews of assumptions that appear to prevail in guiding – and indeed constraining - thinking about what is possible for young children in the realm of scientific reasoning (e.g., Brown, Campione, Metz, & Ash, 1997; Metz, 1995). Candidates include: young children’s lack of general knowledge with which to reason, processing constraints due to perceived limitations in capacity, and assumptions about development and learning, principally informed by erroneous inferences from the writings of Piaget. While it would be naive to ignore the potential role of these constraints in planning, enacting, and evaluating instruction for young children, it also behooves us to realize that, as a field, we have few systematic investigations of what is possible when young children are provided compelling reasons to engage in scientific investigation, a social context in which they are supported to learn about scientific reasoning, and access to tools that have been designed to support their thinking and learning about science.

This brings us to the results I report in this chapter; research designed to inform our understanding of children’s learning in the course of guided inquiry science instruction. Specifically, I have been examining teacher and student discourse and activity in primary-grade classrooms pursuing units of study that are designed with an eye to how scientific inquiry can be experienced by young children in the service of advancing their understanding of key concepts. Furthermore, I have been a participant in the development of a particular tool that is intended to support teachers and their students in the activity of scientific reasoning; a form of text that referred to as a Notebook Text (Magnusson & Palincsar, in press; Palincsar & Magnusson, 2001), in reference to the fact that the text has been modeled after the notebook of a fictitious scientist.
The question guiding this analyses reported on in this chapter is: How do primary grade students, engaged in inquiry experiences, respond to various mediational means (materials, texts, teacher support) designed to advance their development of conceptual understanding and scientific reasoning?

FINDINGS

I have chosen to report my the findings by examining the relationship between our data and claims that have figured prominently in the educational and developmental psychology literatures on young children engaged in scientific inquiry.

Using Data as Evidence

Making a link from quantitative data to a relationship between variables that correspond to aspects of the physical world is not a trivial matter but is certainly a fundamental aspect of inquiry in the physical sciences. Gott and Duggan (1996) argue that having “concepts of evidence,” such as knowing how to use tables and graphs and thinking about variable manipulation, is at least as important as developing understandings about “substantive” scientific relationships such as the relationship between an object’s mass and its speed going down a ramp. Arguing for school science instruction to include explicit reference to such “concepts of evidence” they write:

“evidence is the medium of communication between scientists, engineers and informed citizens on the one hand and issues in the reality of everyday life which involve science on the other. ...the human face of science, the point at which it interacts with people's lives in anything other than a paternalistic explanatory fashion, relies absolutely on the participants being familiar with the language of evidence and its knowledge base” (Gott and Duggan, 1996, p. 795).
Millar, Lubben, Gott & Duggan (1994) elaborate on the difficulties children experience making decisions about using and interpreting quantitative data. Working with year 4 – 9 students in British schools (roughly corresponding to U.S. grades 3 – 8), they found great variation in children’s abilities to see a correspondence between a measured variable and the physical phenomenon it represented. These researchers suggested that much of this difficulty stemmed from children’s difficulties understanding quantitative data from continuous variables (they tended to treat them in a categorical manner and use qualitative labels).

In the *Motion* unit of study, although the class never used the word “evidence,” they were engaged in using data as evidence to address a particular question. This was new territory for these young children. Over the course of instruction, the children had multiple opportunities to examine and engage in interpretation of data tables. In the next section I detail the nature of these opportunities, the challenges these opportunities posed, how the children were supported in interpreting and using data to explore and generate knowledge claims, and how their use of data tables changed over three points in the instructional unit.

**Initial encounter with a data table.** The first notebook text, entitled, *Sledding down a Hill, Rolling down a Ramp*, was used to launch the unit of study on motion. In the course of responding to the first two pages (Figure 2), the children had expressed their opinions about whether the sledders would reach the bottom of the hill together or whether one would be faster than the other. On pre-assessment items that assessed children’s thinking about the relationship between mass and speed on an inclined plane, the majority of the class answers indicated that they thought a heavy and light ball would reach the bottom of a ramp in different amounts of time. However, the book’s illustrations showed that, despite the difference in the sledders’ weights, they had reached the bottom of the hill at
the same time. This scene prompted Lesley to ask “Will something heavy and something light always get to the bottom of a hill in the same amount of time?”

The subsequent pages of Lesley’s notebook showed how she had decided to model this question by using 2 balls of differing mass to represent the sledders and a ramp to represent the hill. On page 7 (Figure 3a), just before the first data table, the children saw a series of views of the balls going down the ramp. Page 7 was designed to have the children compare the balls at three time points – at the top of the ramp (0 seconds), part-way down (3 seconds) and almost at the end of the ramp (6 seconds). Page 8 (see Figure 3b) included a data table showing the speeds of the 2 different balls rolling down a ramp. The text above the data table read, “I recorded my measurements of how long each ball took to get to the bottom of the ramp” and after the data table, Lesley asked herself “What did this tell me?” Over the course of the first two days of the instruction, the class spent the vast majority of the instructional time (approximately 1 hour and 20 minutes of 2 hours) on this one page.

Before we turn to our analysis of the instruction, it is helpful to consider the complexities the children confronted in interpreting this table. One challenge arises from the children’s entering conceptions about the relationship between mass and speed in an inclined plane context; Lesley’s data were, for most of these children, counterintuitive. There were the complexities of simply decoding the table; that is, recognizing what the labels stood for and determining what information was presented in each cell. There were the demands associated with making sense of the formal representations; for example, understanding the relationship between time and how time is represented in numbers; and recognizing that the higher the number corresponding to the time interval, the slower the

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1 We have since revised this question to be “Can something heavy and something light get to the bottom of a hill in the same amount of time?”
speed of the ball. Finally, there were demands on the children’s working memories (i.e., keeping in mind the multiple variables such as mass and speed and the times across trials). With these challenges in mind, I turn to analyses of the instruction.

As Mrs. MacLean presented page 8, she said to the children:

OK, so...she [referring to Lesley] thought, “Well, maybe I’ll make several trials. Maybe this is not...this may not happen again.” She still wasn’t sure. Will the ball that’s lighter and the ball that’s heavier go down the same amount of time? So she had to do some other things. And she made a table.

Using her finger, she pointed to each of the cells of the table as she said:

She tried 4 times to roll these balls and the first trial... the lighter ball which is 10 grams went down 8 seconds. A second trial it went down 7 seconds. ...(a child says something inaudible) Well, you can read that, right? With that trial (pointing to the third trial row) it was 7 seconds. The fourth trial it was 8. (Pause) Now, she did that with the heavier ball, which is the 50 gram ball. So, (pointing to each cell in the column for the 50 gram ball) the first trial went 7 seconds... second trial it went down 8 seconds... the third trial it went down 8 seconds... the trial the fourth time it went down 7 seconds. And then she looked at it and asked herself... everybody read what she asked herself.

Children: (reading as Mrs. MacLean gestures along the sentence) What did this tell me?

The children then read the next sentence as Mrs. MacLean moved her finger along it, and she directed the children then to look at the table, “just like she (referring to Lesley) probably did, and see, what does the table tell you?

I infer from Mrs. MacLean’s presentation of the table in the text, that she did not assume the children would be able to immediately understand what the numbers in each cell represented. She made a point of going through the entire table and talking about what the data in each cell corresponded with (i.e. how long it took each ball to reach the
bottom of a ramp). She then focused the children’s attention on the purpose for which the table had been constructed – to address the question of whether something heavy and something light would reach the bottom of a hill in the same amount of time.

The first child to respond, however, did not make this link, instead he looked at the numbers themselves and said “It’s like a pattern.” When Mrs. MacLean asked him what the pattern was, he simply read off the numbers “8, 7, 7, 8, 7, 8, 8, 7.” Mrs. MacLean accepted this response by acknowledging that “it’s sort of like a pattern” and elicited additional responses to the question “what does the table tell us?” The next child to respond indicated that the numbers in the data table corresponded to a physical phenomenon. She also used the data to make a statement comparing the numbers in terms of relative speed.

Sandra: It (the table) says that sometimes it took longer

Mrs. MacLean: Oh, are you comparing the two trials?

… (Here Sandra talks about the numbers and compares the numbers across the rows of the table, but her voice is very low and on the videotape her exact words are indistinct.)

Mrs. MacLean: O.K., well, Sandra said that sometimes... she’s looking at it this way (Mrs. MacLean gestures here to the results across the table – between the big and little balls), she said sometimes the little ball went there faster or slower, sometimes it went faster than the big ball, sometimes it went faster than the big ball and sometimes it went slower than the big ball. Does that tell you anything about either one?…What can you say about that? Ava?

Ava: They used 8 and 7...

Mrs. MacLean: It’s just 8 and 7 seconds. O.K.

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2 Because of the way the numbers were arranged in the table it was actually impossible to tell if he was reading the numbers down the columns or across the rows.
Here Mrs. MacLean attempted to elicit more children’s interpretations of the numbers, but Ava’s response reveals that she was still focused on the numbers, without recognizing their relationship to some physical phenomenon. Ava’s observation: “they used 8 and 7” suggests that she did not have a clear sense of what purpose the data table served or how it had been generated.

At this point Mrs. MacLean ended Day 1’s lesson; however, that afternoon she asked the children to write about what they thought the data table showed. The next morning, after a quick review of the first several pages of *Sledding down a Hill, Rolling down a Ramp*, she shared some of the children's written responses to the table with the whole class. She especially highlighted children's writing about which she had questions, for example:

Mrs. MacLean: ….I didn't understand this...can I ask this uh,... Josh?  It said, (reading from Josh’s paper) "The balls got to the bottom of the ramp at the same time, but in different order.” Did you think that they were both going down at the same time... each time?  What did you think, hon?

Josh: Uh...They're going down at different times.

Mrs. MacLean: They went down at different times. O.K., and there was something interesting here. (looking at another of the children’s writing) Jeffrey...

Jeffrey and Matt (these two boys had worked together to write their responses)... now, you have to explain to us what you meant by this... oh, this is where I said... this is what Jeffrey says... (reading) “when Lesley put the balls on the ramp they stayed together”... that’s the first ramp. (reading again) “But, on her trials one would get there before the other.”. because you were thinking that they were always together... is that why you said that?

(Jeffrey nods.)
Mrs. MacLean: Oh, O.K. I think that’s what you were... because there were two
together... one would get down there before the other because you were
looking at the numbers side by side. Is that what you were doing? O.K.,
now I understand what you were saying.

The children’s writing indicated that they were confused about how Lesley had
derived those particular numbers in her data table. The children were not able to make the
translation back from Lesley's quantitative data to the procedure with which she had
collected the data. Thus, despite a conversation the day before about the difficulty of
timing two balls at the same time, some children continued to imagine that Lesley had put
both balls on the same ramp and tested their speeds simultaneously while other children
thought Lesley was using two different ramps. In other words, the class did not have a
shared understanding of what the numbers in the table represented, nor of the context in
which these data were generated.

Realizing this, Mrs. MacLean turned to helping the children understand what Lesley
had done in several ways. First, she asked the children to think about the language of the
table, specifically what the word "trial" meant in this case. In response to the teacher's
question, "What's a trial anyway?" one child indicated that another word for trial is
"time." Mrs. MacLean then consistently used the word "time" (as in 1st time, 2nd time,
3rd time...) in a replica of Lesley's table that she drew on the chalk board. She drew the
replica next to the posted notebook page.

Next, she had the children pantomime what Lesley must have done to test the speed
of the lighter ball, whose data were presented first in Lesley’s table. Each child pretended
to hold a 10g ball and raised their hands to simulate putting the ball at the top of the
ramp. Then they let go. When Mrs. MacLean said "stop," the children looked to the data
table page to tell how many seconds "the ball" had taken to go down. As they did this,
Mrs. MacLean filled in the data on the new data table (see Figure 4).
After going through this process of deconstructing and then reconstructing the data table, there was evidence that at least some children in the class had acquired a robust understanding of what the numbers in Lesley’s data table represented. Here is what happened in response to Mrs. MacLean’s question “How long do you think it took for it to go down?”

Child: 8 and 7 seconds.

Mrs. MacLean: 8 and 7 sec... can we put the one number to it, or is it possible? Tina?

Tina: 7 seconds?

Mrs. MacLean: Well, how about if we say almost sort of 7 and 8... can we say it that way?

Child: Both!

Mrs. MacLean: It’s both. All right.

Although one wouldn't expect second graders to talk about "statistically significant" differences among data, at least some members of the class were able to come to the conclusion that 8 seconds and 7 seconds were really about the same amount of time in this case.

Following this day of instruction, Mrs. MacLean again asked the children to write in their notebooks in response to the question, “Will something heavy and something light always get to the bottom of a hill at the same time?” Mrs. MacLean was adamant during this writing that the children should use the data table to answer Lesley’s question. During almost every individual interaction as the children wrote, she first focused each child’s attention on Lesley’s question and then asked him or her to make a distinction between what the child might personally believe and how the data from the data table addressed the question. Here is a portion of a typical example of how Mrs. MacLean posed the task to a child (underlining signifies emphasis):
[Talking to one child while that child is working on a written reflection] Think about the question. Will something heavy and something light always… O.K.

Looking from this table, not from your head, from this table... does this table say anything about... answer the question. What is this table’s answer to that question. If you think about this table... how does it answer the question? Are they coming down in the same amount of time or are they not? Well, that’s what I want you to write. Because that is what I want you to think about. What is this table’s answer to that question?

This push and stress to focus on “this table’s answer to the question” is reflected in most of the children’s responses on Day 2. Although a few children used the table in this way on Day 1, far more did so on Day 2; in fact, 9 of the 15 children for whom there are notebook entries stated that weight did not affect speed. Only three children maintained that the balls had reached the bottom of the ramp in different amounts of time and the remaining three children’s beliefs were indeterminable as their notebook entries were either incomprehensible or simply restatements of the numbers on the data table. Bill’s entries are representative of the change in many of the children’s thinking from Day 1 to Day 2. On Day 1 he believed that weight would affect speed:

*I think that something heavy and something (something) light will’t (will not) roll down at the same tim(time) and not tie by rolling down a ramp because they are different.*

Here, Bill was focusing on the issue at hand – the differing mass of the balls and their speeds. He also suggested that the reason for his statement that something heavy and something light would not “tie,” was because the balls “are different.” While this not what a physicist would think, Bill did offer some justification for his belief. On Day 2 Bill wrote:

*They went down at the same time but at different Trial. the Table Told me that the The 10 gram ball and the 50 gram ball are as fast and as good as each other. The 10 gram ball can go as fast as the 50 gram ball. It does not matter the Waight (weight).*
Although Bill still did not yet express a scientific reason to explain why weight would not make a difference in this case, he used the data table to conclude that the 50 gram and 10 gram balls were “as fast and as good as each other.” His notebook entry indicates that he had learned to read the data table and make an interpretation of the data to answer a specific question.

We see a contrasting case in Adam’s writing. On Day 1, Adam’s notebook entry read: “The data Lesley made tells me that the ramp mate may of not been the same ramp.” With the writing, there is a diagram of a 50 g ball and 10 g ball, which are labeled, poised at the top of two different ramps -- the ramp with the 10g ball is lower.

As was the case for a number of students, Adam did not have an accurate understanding of the question Lesley was asking, nor of the procedure she had used. The context he represented suggested that he thought a lighter ball traveled faster than a heavier ball down the same ramp, and raising the height of a ramp would make the heavier ball travel faster. Thus, he accurately represented the outcome in Lesley’s table (equal times for balls of different mass) from the perspective of his prior knowledge. By Day 2 Adam no longer believed that Lesley had used two different ramps, and his writing indicates that he was reading the data across the rows, comparing the results for the balls at each trial. While doing this, he observed that the 10g ball and 50g ball “never tied.” Perhaps, despite the pantomiming activity the class had engaged in, Adam still thought the balls were going down the same ramp at the same time as opposed to separate times. He therefore used the data table to say how he thought the speeds were different.

\[ \text{the table told me that never tied. So I thank the tie was wrong}. \]

The details provided above illustrate the nature of the children’s difficulties interpreting a data table and using data as evidence to address a question in the absence of concrete representations of what occurred or concrete experiences of the same type. We also see many of the children focusing on the task at hand – using data as evidence to
address a question – although we might not agree with their interpretations. In addition we see the range of strategies Mrs. McLean drew upon to mediate the children’s experiences working with these data, including engaging in a simulation of the investigation accompanied by a reconstruction of the table.

Comparing sets of data. On Day 5, the focus of inquiry shifted from the relationship between mass and speed down a ramp to the relationship between the height of the ramp and the speed with which balls of the same mass would travel. The class had constructed two data tables, one set gathered when the ramp was two blocks high and the other when the ramp was four blocks high. In the following example, the children were interpreting the data for the purpose of identifying patterns that would lead to claims about the relationship between ramp height and speed. What is notable is the facility with which children in the class decode the table and use the information to generate knowledge claims:

Mrs. MacLean: Look at the numbers when we had 2 blocks high and look at the numbers when we had 4 blocks high. [Pointing to the data for the ramp that was 2-blocks high] They were going down four seconds or five seconds each time.

Child: I agree.

Mrs. MacLean: And in the four blocks, they were going down two to two and a half or three seconds each time. But if we compare the two tables, what do they tell us? … Jamie?

Jamie: If you raise it up, the block on the ramp, then it will start to move shorter.

Mrs. MacLean: O.K. What is shorter?

Jamie: It will go faster.

Mrs. MacLean: O.K. Jamie says, “If you raise the ramp, the ball will go faster.” O.K., Eddie what did you say?

Eddie: If you lower the ramp, it will go slower.
Mrs. MacLean: If we lower the ramp, the ball will go slower.

Jamie: Well, that’s what I meant. I meant.

Mrs. MacLean: Well, either way is fine. Yes, Adam?

Adam: I think, uh, with the 2 blocks, it’s lower so, uh, the 2 blocks won’t give it much power to go fast but at 4 blocks it will be high enough so it will go fast.

Mrs. MacLean: You think, uh, he says, “When it’s low, it does not have enough power to go fast.” O.K. Where does it get its power, I wonder. (starts a list of ideas on the board)

Child: Oh, how high the blocks are.

Mrs. MacLean: I’m going to write the . . . Power from the height? O.K.

. . .

Adam: Power from the steepness and the balls gain power. (Mrs. MacLean writes this phrase)

Mrs. MacLean: O.K. Power from the height or the steepness. We call the power energy.

It has more energy to go fast when it’s higher. Is that what you’re saying?

Adam: Yeah.

Mrs. MacLean: So when it’s low, it doesn’t have as much energy. O.K. I wonder what it does . . .

Adam: It doesn’t have enough power. It doesn’t have enough power.

Mrs. MacLean: It doesn’t have enough power. Can we use energy as uh, for power?

During this discussion, several children offered interpretations of the data. Mrs. MacLean pressed Jamie to clarify what she meant by saying that the ball "will start to move shorter." Her response that she meant "faster" opened the floor for Eddie to suggest the corollary: "If you lower the ramp, it will go slower." Adam then expanded on these statements to suggest a possible cause for the differences – a potential difference in the
amount of "power" the ball has. This notion of "power" was a useful way of thinking about the situation with the balls and ramp. The inclination to engage in causal explanations is consistent with the findings of psycholinguistic studies of young children's use of causal explanations, suggesting that by the time children enter kindergarten they are quite competent at making a variety of connections between evidence and theories; they are asking questions about causal relationships; and they are beginning to be able to put together more than one piece of information to predict an outcome (Bloom & Capatides, 1987; Callanan & Oakes, 1992; Callanan, Shrager, & Moore, 1995; Crisafi & Brown, 1986; Donaldson, 1996; Frye, Zelazo, Brooks, & Samuels, 1996; Hood & Bloom, 1979; McCabe & Peterson, 1985; Orsolini, 1993a; Orsolini, 1993b; Veneziano & Sinclair, 1995).

Mrs. McLean took this opportunity to seed the conversation with a term/concept that has currency in scientific explanations for force and motion, “We call the power energy. It has more energy to go fast when it’s higher.” Clement’s (1993) research speaks to the value of building upon the kernels of ideas that learners bring to their understandings of phenomena. Furthermore, in a study focused on children's language use in school science contexts, Curtis and Millar (1988) found that as children's language becomes more sophisticated, they are able to both develop and express richer conceptions about scientific phenomena. While one would not typically introduce potential and kinetic energy in discussions of motion with primary grade children, having been introduced to the role of energy will serve these children well when they revisit force and motion in subsequent years.

Adam drew on this new understanding in his next notebook entry in which he shared his current thinking about the relationship between ramp height and speed (see Figure 5). The children continued to refine their understanding of the role that “power” or “energy” plays in understanding motion, and brought these ideas to bear in their next
investigation in which they examined whether the speed (as determined by ramp height) affected the distance a can at the bottom of the ramp would move when hit. We see this idea of "energy" reflected in a number of the class claims for this investigation:

- The higher the ball, the more power (energy) it has to go down.
- If the ramp is low, the ball will not move the can very far.
- If the ramp is medium height, the ball will move the can a little bit farther.
- If the ball is higher, the ball can go faster and will hit the can farther.
- If the ramp is higher the ball will have more energy and have more momentum to go farther.
- The higher the ramp, the farther the can moves when it’s hit by the ball.
- The lower the ramp, the less the can goes.

What is significant about the language the children used is that it reflects the ways in which they were gradually building an understanding of "energy transfer" which is, in fact, a fundamental concept for understanding motion and the interaction of objects in motion.

**Final encounter with a data table.** By the end of the 10-day unit of study on motion, we see further evidence that children in the class had become adept at interpreting data to advance their inquiry. On this last day of the unit of study, Mrs. MacLean’s class reviewed what they had been discussing the day before. Mrs. MacLean began by saying:

Remember yesterday? We looked at her (Lesley Park's) question… her new question... (reading from Clowning around Under the Big Top: Moving Energy from Here to There, page 7) “Does the mass of a ball make a difference in how far an object that it hits moves?” And she got that idea from the big… you know, from the clown act. And I asked you to write down what you think and I had some who thought, “I guess it might make a difference” and the reasons were mostly “because the heavier ball is stronger.” But, most of you decided that, “no, it doesn’t make any difference” because in the first
book, she (meaning Lesley) discovered that mass did not make any difference in how much time... or the amount of time the object will go down a sled or a ramp. And remember when I asked the question...(brief interruption at the door). If a large person went down the ramp and… you decided that you… will go down together… at the same time. O.K. so, now she said… she’s thinking of a different question. The mass did not make any difference in the amount of time going down…is it going to make a difference in how far the object is going to get hit?

The new question Lesley was asking in her second notebook was about the relationship between mass and momentum. Recall that Lesley came to this question because of the circus act she had seen (as depicted on the first page of *Clowning Around*, see Figure 6) in which the cake box failed to reach the elephant. This situation prompted Lesley to think about how she could get more energy to the cake box. Drawing upon their own first-hand experiences investigating motion down ramps of varying steepness, the children in Mrs. MacLean’s class immediately suggested changing the height of the ramp, but that had been ruled out as impossible in Lesley’s notebook.

--------INSERT FIGURE 6 ABOUT HERE--------

Lesley proposed changing the mass of the cart; however, many of the children were skeptical about this idea because, in the first big book and in the class’ own first-hand investigations of mass and speed, mass had been determined NOT to make a difference in how fast balls rolled down a ramp. Jeffrey’s writing about whether mass would make a difference in the new clown-cart situation showed the influence of his own first-hand experiences:

“I think the mass or the weight dose (does) not matter. Because we tryed (tried) it with a big ball and a little ball and they got to the end at the same tim (time).”
A second child, Jamie, referred to Lesley’s first notebook text to justify her opinion:

“I think mass doesn’t make a difference in how the object moves. I think that because in the first book there were sledders (sledders) and they got to the bottom at the same amount of time and they were different (different) weights.”

Sandra expressed the most strident skepticism of Lesley’s suggestion that changing the mass of the cart going down the ramp might affect how far the cake box was moved:

“I think that Lesley Park is wrong. You see in page 7 in number 2 book she thinks that weight matters. In book number 1 we figured (figured) out that the weight does not matter.”

She then went on to offer an alternative suggestion that involved a transfer of energy:

“In book number 2 we are trying to figure out what the circus (circus) cart with the clown (clown) has to do to get the cake to the elephant. This is what I think: The clown (clown) at the top of the ramp has to push the cart with the clown (clown) harder. If the clown (clown) pushes (pushes) the cart harder then it will give the cart energy to give the cake energy to move to the elephant! That is what I think. The End”

Other children agreed with Lesley that mass might make a difference in how far the clown car would be hit. For example, Trevor, who struggled with writing, wrote:

“the little ball doesn’t Go dawn the Can a mt a Kos the Big is srqlr thynr the little ball…” (on this same page in Mrs. MacLean’s writing, we have what Trevor read that he had written: The little (ball) cannot hit the can far because the big ball is stronger than the little ball.”

Jason not only supported Lesley’s notion that weight could affect how far a can would be hit, he also wrote a hypothesis about how the energy would be transferred to the cake box:
“yes the mass dos (does) make a difference in howe (how) far an object that it hits moves because (because) the wate (weight) gives it more enrgy (energy) and give the thing that it hits (hits) and gives the energy to the thing that it hits to make it go far.”

From these journal entries we can see that children in the class were grappling with the aspects of the new question that were the most pertinent: the balls’ mass, and the issue of energy getting to the cake box. Many were able to articulate their thinking about relationships among variables in the situation and often gave justifications for why they thought about the relationships in particular ways.

So facile had the class become with the issues at hand that when Mrs. MacLean proceeded with the lesson, it only took only 10 minutes to talk about: (1) the experimental set-up to test whether a ball’s mass would affect how far a can at the bottom of a ramp would be hit, (2) how to collect and display the data that would be collected, and (3) how Lesley could ensure that she would conduct a “fair test.” After all this was sorted out, the class spent a few minutes predicting how far the can would be moved when hit by a 10g ball and by a 100g ball. At this point there was a discrepancy between what the children had written in their notebooks and the predictions they made for the two balls. In their notebooks most children had written that the mass of the balls would not affect the distance the can was moved, but in their predictions only two children maintained that the distance would be the same regardless of the balls’ mass. The rest of the children predicted that the heavier ball would move the can further. And, indeed, Lesley’s data supported this idea. When the class then examined Lesley’s data they reached the same conclusion that Lesley did -- the balls’ mass did affect the distance the can moved.

In her notebook Lesley then defined a challenge for herself. On page 10, she wrote “If I really understand how mass affects momentum, I should be able to predict what will happen with a different mass.” On page 11 she set up her data table to record her
predictions for a ball with a mass between 10g and 100g. In this case, she chose to predict for a 50g ball.

Before seeing what Lesley had predicted, Mrs. MacLean asked her class to predict what would happen with a 50g ball and she recorded each child’s predictions on a separate sheet of paper, which she taped to the column for the 50g ball (see Figure 7 below). The children’s predictions ranged from 10cm to 71cm with the vast majority between 40cm and 65cm. All but one child predicted that the distance for the 50g ball would be between the distances the 10g ball and 100g ball had traveled. Two of the children (who had predicted 44 and 43) justified their predictions by pointing out the numeric relationships between the distance the 10g ball had gone and the distance the 100g ball had gone. They had then estimated that the distance the 50g ball would go would be about half way between the distance the 10g ball had gone (about 20cm) and the distance the 100g ball had gone (about 86cm). As Adam said: “...because half of 100 is 50 and half of 8 would be 4 and half of 6 would be 3.”

After lifting a flap on page 7 to see Lesley’s prediction (40cm), Mrs. MacLean posted the next page of the Big Book on the board (See Figure 8). The top half of this page featured a data table that included the results from 4 trials with the 50g ball.

Mrs. MacLean: Look what happened!

(Children excitedly talking)

Mrs. MacLean: O.K., so that’s what happened when she did that. O.K., take a look at it and think... think it... O.K. Well, actually your predictions were at least between these and that (pointing to the columns for the 10g ball and the 100g ball), but if... I see a... a few that came close. Let’s do all the 4’s.
(Mrs. MacLean took the children’s prediction sheet and circled with a red marker all the predictions that had been in the 40’s)

Child: There was a 43 there.

Mrs. MacLean: I know. Well, you think she only did 4 trials, but she had a 45, 47, 45, 43... she thought it would be 40... well they were a little bit more, but somewhere there...

At this point in the instruction, the children did not require explicit scaffolding to read the data table and compare their predictions to the results of Lesley’s experiment. Their examination of this table took all of about a minute and the class then turned to the second half of this page (which had been covered up) to examine a line graph Lesley had made of her data. They then went on to generate a set of claims about the effect of mass on the distance a ball would be hit and about the way energy was transferred in this situation (already listed above). With the competence the children displayed interpreting data tables, Mrs. MacLean had raised the ante, engaging the children in a thought experiment in which they interpolated data.
Evaluating Investigative Procedures

If Millar and Kragh (1994) are correct that "understanding what is involved in collecting reliable empirical evidence is at the heart of all scientific investigating" (1994, p. 34), then children need opportunities to develop an understanding of how and why data are collected as well as how to evaluate data to determine if they can be used to support claims. In the following example, I illustrate how the notebook text was used to introduce these young children to several significant aspects of investigative procedure: the design of unconfounded experiments through careful attention to the control of variables, and accounting for variability in data when running repeated trials.

**Designing a fair trial.** Chen & Klahr (1999) determined that, even given repeated opportunities to learn control of variable strategies, fourth graders correctly constructed unconfounded experiments less than 50% of the time. Mindful of the importance of this knowledge and the challenge students experience acquiring this knowledge, the GIsML team incorporated the following opportunity in the first notebook text: Lesley showed a diagram of the set-up she used to test the speed of 10g and 50g balls. Each piece of the set-up was labeled, as was the starting line on the ramp. Lesley’s written entry on this page asks: "What do I need to do to have a fair test?"

The class’s conversation as they responded to Lesley’s question was quite revealing. When Mrs. MacLean asked the children where Lesley should place the balls in order to have a fair test, the children were divided among those who thought the balls should each be placed at the "starting line" and those who thought that the small one should get a head start to make the result "fair."

Mrs. MacLean: There we go.. so, in order to have a fair test then.. so she’ll know exactly if they’re going down the ramp at the same time or different times.. she asks questions to herself. “What do I need to do to have a fair test?”
O.K., here we go. . . . So … where would she put the ball. behind the line or on the line?

Child: On the line.

Mrs. MacLean: Yes, Marvin?

Marvin: Behind the line.

Mrs. MacLean: Behind the line. So that when it starts to roll down it would be starting from the line you were saying? Does anybody agree with that? Who agrees that the ball should be behind the line? Now, how about the little ball? Should the little ball be behind the line?

Children: Yes.

Child: No.

Mrs. MacLean: Who said no? Somebody said no. Philip, you said no. Where should the little ball start from?

Philip: The middle.

Mrs. MacLean: The middle. Why?

Philip: Because, probably the heavier one would go down faster, so it wouldn’t be very fair.

Mrs. MacLean: O.K., Philip still believes that the big ball will go faster so it should start there [pointing to the starting line], but the little ball should start where?

Philip: The middle.

Mrs. MacLean: In the middle. Why should it start in the middle? We are trying to see if they are going to go down [in] the same … amount of time. If … the little ball starts down there and we don’t know.. I mean, the little ball would be going a little bit shorter, don’t you think? So shouldn’t we have the little ball up there too?
Child: Yeah.
Child: No.
Mrs. MacLean: Yes, um..
Jamie: I think we should.. I think we should start both of them right on the line.
Mrs. MacLean: O.K. Jamie said they should.. both of them on the line. Why?
Jamie: Because, that’s the start.
Mrs. MacLean: O.K., that will be more fair if they start together

This excerpt is an example of how at least one child (Philip) brought his everyday understandings of the word “fair” to his sense-making within this scientific context. Through discussion, the class was able to come to consensus about the where the starting place for the balls should be and perhaps a bit closer to understanding the meaning of "fair" as used within the scientific community.

**Accounting for variability in repeated trials.** The reader will recall that in her first notebook, Lesley’s data for the 4 trials with the 10g ball yielded different times (varying between 7 and 8 seconds). Mrs. MacLean took advantage of this feature to ask: "I wonder why it was not always the same number of seconds?" With this question, the children began to consider possible sources of variation in data such as experimenter error. The class generated a list of possible reasons why the 10g ball had not always rolled down in the same number of seconds. Figure 9 shows what Mrs. MacLean recorded of the children’s ideas, and the following transcript presents the conversation between her and the children.

---------INSERT FIGURE 9 ABOUT HERE---------

Kelly: Oh maybe she put the ball higher one time?

Mrs. MacLean: Did you hear what Kelly said? Maybe she put the ball higher (rising intonation on higher) one time. That would change the numbers
wouldn’t it Kelly? Wow. Good thinking. Any other thinking? Tina?
Yes, Jeffrey?

Jeffrey: Maybe a window was open and the wind was blowing it.

Mrs. MacLean: Maybe there was wind blowing…

Molly: Maybe a pet pushed the ball.

Mrs. MacLean: Well, you know she’s in.. I think she was in her lab and she doesn’t allow pets because she’s not studying pets. Just balls and ramps, that’s all. Yes, Philip?

Philip: Maybe she uh, accidentally pushed it a little harder..

Mrs. MacLean: Pushed what?

Philip: The ball.

Mrs. MacLean: She could have pushed the ball, yes. O.K. (writing) “Ball”.. anything else? Now we’re thinking! Yes, Trevor?

Trevor: Maybe she dropped the ball lighter than harder.

Mrs. MacLean: O.K., so it had to do with the way she let the.. why don’t we just say “the way she let the ball go,” is that.. is that O.K.? (long pause, writing on sheet) O.K. Yes, Tina?

Tina: Maybe she bumped the table.

Mrs. MacLean: O.K.

Child: I said pushed.

Mrs. MacLean: Pushed.. O.K. Yes?

Child: Maybe she..

Mrs. MacLean: Wait.. wait.. wait.. I need some other hands. Yes, Ava?

Ava: Uh, maybe she had 2 ramps and she had used.. she switched them back and forth or something.
Mrs. MacLean: Wait.. remember we’re just using 1 ramp and 1 ball at this
time. O.K.? How about Marcus? Yes?

Marcus: Maybe she like dropped it quickly and it like.. it had like, she had a little
bit longer ramp?

Mrs. MacLean: O.K., Adam?

Adam: Maybe she pushed the ball the first time a little bit and the second time
she let it go too easy and the third time she let it go too easy and the last
time she might have pushed it a little.

Mrs. MacLean: So, can we think of that as the way she let the ball go? That maybe it
was pushed a little the next time.. Yes, Trevor?

Trevor: Maybe the ramp was shorter than longer?

Child: No, they’re just using the same ramp.

Mrs. MacLean: It’s the same ramp, remember that? Yes?

Jeffrey: Maybe she sneezed.

Mrs. MacLean: How about the stopwatch? Do you think maybe there is something that
had to do with the stopwatch?

Jeffrey: Maybe it’s out of batteries.

... 

Jason: Maybe she pushed it too.. a second too late?

Mrs. MacLean: O.K., the one time. O.K. Uh, how about (writing) “pushed stopwatch
sometimes late and sometimes early,” you think?

Child: Yeah.

Mrs. MacLean: (writing) “Sometimes late and sometimes early.” O.K. Boy, this is
really a hard thing to do when you’re just thinking it and not doing it,
isn’t it? But, you’re doing a great job. (pause) Yes, Philip?
Philip: Maybe when it’s... she pushed the watch too late maybe she was looking away because uh, something happened?

Mrs. MacLean: Yeah.. But that would be in the way of pushing.. Oh, O.K., the way she let the ball go would that be about the same? O.K., everybody now look here. Now, is that.. is that perhaps the reason why she had to do it several times to make sure?

Unencumbered by the demands of conducting the investigation themselves, the students generated a broad number of possible explanations for the variability in Lesley’s data. In the next and final example we examine how the students interpreted data that were presented via a line graph and coordinated this presentation with other data representations.

Making Sense of Multiple Forms of Representations

In the course of first- and second-hand investigations, children are challenged to both interpret and generate multiple forms of representations. In the examples provided thus far, we saw how the students learned to interpret data tables and engaged in evaluating investigative procedures. I turn now to a description of how the class used two different but similar representations of data, one during a first-hand investigation, and the other during the final second-hand investigation. To provide a context for examining the children’s use of these representations, some description of how the children were thinking about some of the scientific concepts and scientific procedures at play at this point in their unit of study is warranted.

Until Day 6 of the unit of study on motion, Mrs. MacLean’s class had been focusing on the speed of balls going down a ramp when either the mass of the balls or the height of the ramp was varied. On Day 6, Mrs. MacLean asked the children to consider what might happen if a ball hit a can at the bottom of a high ramp or at the bottom of a low ramp.
One child (drawing upon his earlier investigations of ramp height) indicated that the ball coming off the higher ramp would hit the can harder and move it further. A second child concurred, adding that the ball from the higher ramp would have more energy.

After some more discussion of this idea, the majority of the children expressed views which corresponded with the hypothesis that a ball rolling down a higher ramp would hit the can further. Only one child raised her hand when Mrs. MacLean asked if there were other opinions. Alexis said she wasn’t sure what would happen, and Mrs. MacLean responded: “Alexis doesn’t think that this one will be ... will go farther. Is that what you’re saying? Or you’re not sure? She’s not sure. Oh, good! We can try it.”

Thus, the class proceeded to figure out how to conduct a test of the problem. Having discussed how important it would be to change only one variable, the ramp height, the class quickly decided to use one ball and one can and vary the height of the ramp by putting different numbers of blocks under one end of the ramp. With the actual materials in the center of the Big Space, Mrs. MacLean then posed another kind of problem: How could they document their findings? After several children had suggested and tried out a variety of ways to use rulers taped to the floor, Jeffrey said “We could get a book and do it.” Mrs. MacLean chimed in that maybe a piece of paper would work and Sandra added that “On paper we could ... use like a mark.” The children were excited and several called out “How could that work? How could that work?” Mrs. MacLean then demonstrated the idea for documenting the investigation which she had actually devised during her planning for the unit of study. Yet, even while she demonstrated the method she had tested exhaustively, she continued to ask for feedback and suggestions from the class.

In this method a large piece of white construction paper was placed on the floor one block length away from the end of the ramp. The midpoint of the piece of paper was lined up exactly with the groove on the ramp and the can was placed on the edge of the paper nearest the ramp. There was a notch in the wood at the top of the ramp to show the starting point for the ball. Children raised or lowered the height of the ramp by changing
the number of blocks at one end. When the ball went down the ramp it hit the can at the bottom. The can moved on the paper and the children then traced around the can wherever it had come to rest. These tracings were color coded for each ramp height (see Figure 10a).

The method Mrs. MacLean proposed alleviated the need to use rulers and record numerical results on a separate piece of paper; however, it still allowed for later quantification of the data, as the children could go back and measure with rulers the distances the can had moved. The beauty of the procedure was that it allowed for all the data to be collected on one sheet of paper. Thus, after all the children had worked in pairs to collect data from three different ramp heights (2 blocks, 4 blocks and 6 blocks) their data record sheets had three groups of tracings (see Figure 10b).

Because of material and space constraints, Mrs. MacLean could only have five pairs of children working at a time. Therefore, while some children were collecting data, the rest were working on other tasks and assignments. When a ramp became available, another pair was able to do their data collection. Mrs. MacLean did not set limits on the amount of time a pair could work. It took about an hour and a quarter for all 22 children to collect data.

On Day 7 the class reconvened in the Big Space. Mrs. MacLean started off the lesson with a review of the questions that had been considered over the course of the previous week. Once the class had established the progression of the questions, Mrs. MacLean reviewed with the children the question they were investigating and how they had conducted their investigation. Mrs. Maclean proceeded to post all of the children’s data collection sheets across the length of the chalkboard. Each sheet was lined up next to

3 Also interesting to consider is whether the link between the documentation of the investigation and the actual physical conduct of the investigation was more obvious to the children than, for example, recording numbers in a data table.
another so that there was one long band of data creating a giant display across the board. Mrs. MacLean asked the children to look carefully at the data and “see if there is anything you can notice.” Several comments were about the spacing of the data sheets and one was about the colors on the sheets, but no one spontaneously commented on what the data represented. Mrs. MacLean then asked: “What were we trying to remember by using the different colors?” and Ava responded “How many blocks we used.” This led a review of how many blocks had been used when the can was traced in red (2 blocks), green (4 blocks) and blue (6 blocks). Mrs. MacLean added this information on the board next to data sheets (see Figure 11).

Mrs. MacLean: ... (gesturing to the data sheets) so when we only had 2 blocks, this is how far, uh, the can moved. When we had 4 blocks, this is how far the can moved, and when we had 6 blocks, this is how far the can moved. Is there anything that we can say about that... looking at all these documentation, our data? What can we say about the height of the ramp, and how far the cans moved? The can moved... I think we only used 1 can, each time. Oooh, I like... I can see Jeffrey’s eyes are thinking. Look in there, what is it that we can tell about the height of the ramp, and how far the can moved? Yes?

...

Alexis: (standing in front with Mrs. MacLean) Whenever you use 2 blocks it’s always a certain...

Mrs. MacLean: When there are 2 blocks, the cans were closer than...

Alexis: The 4 blocks and...

Mrs. MacLean: And 4 blocks, and then the 6 blocks.

Child 1: Because they were ... faster.
Mrs. MacLean: Oh, did you hear what he said? The height made the ball go faster, and therefore, they... they went farther. I... I’d like you to use the word momentum. It had more momentum. It’s faster, and we call that momentum. Is that O.K. to use? Yeah. It had more momentum and it was faster. And so the ball... uh, the can went farther.

Child 1: Because it pushed it more.

Mrs. MacLean: It pushed it more. Very good.

--------INSERT FIGURE 11 ABOUT HERE--------

Mrs. MacLean then suggested adding a line across the data sheets:

“Let’s try and make a line through all these things. I wonder what that would show us? .... now, if we made a straight line with red for all the reds, I wonder where we will put it? O.K. Now, .. is this around the middle of this? Shall I make a line to show us something. Now where would be.. where would I put the red there? Meg, where is the middle of yours? We’ll use middles.”

After eliciting the children’s help to decide where to make the “middles” of each cluster of tracings (not always a straightforward matter), she then joined all of these points to create long lines across the entire board and asked the children to think about “what do the lines tell you?”

The children’s initial responses were descriptions of the data rather than interpretations of the data. One child called the lines “a wavy pattern” and another “like the hills.” Sandra then remarked that “…they’re all in the same places.” Mrs. MacLean re-stated what she’d thought Sandra meant:

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4 Though this statement is not technically accurate, I hope the reader will acknowledge that (a) in the fast-paced world of early elementary teaching, anyone can slip up, as well as that, (b) what Mrs. MacLean was probably trying to do was to emphasize for the children that the difference in speed (something a child had raised) is an important variable and part of the concept of momentum, which is an accurate concept to be considering in this context.
Mrs. MacLean: She is thinking that if you look at the lines, the reds... ...she said also the greens and the blues are falling about the same spot... is that what you said?

Sandra: (nodding) Uh huh.

Mrs. MacLean: Now look at them. Do you agree with her?

Child: Uh huh.

Mrs. MacLean: Well look at the lines, do the lines ever meet or crisscross?

Child: No.

Mrs. MacLean: No. So, she said that the blues are about the same spot, the reds are about the same spots, and the greens are about the same spots. And she thinks that that is because the heights are all the same. Is that what you are thinking?

Sandra: Yeah. The blocks are the same, and the height.

Mrs. MacLean: The blocks are the same height, is what she’s saying.

Although most of children the responded that they were able to understand what Sandra was saying, they did not have a response when Mrs. MacLean asked “So what can we say about the height of the ramp and how far the ball will hit the can?” Perhaps Mrs. MacLean had expected the children to be able to interpret the data as fluently as they had the data tables for the ramp-height/speed investigation because she herself could see the connection between the results on the board and the physical phenomenon from which they were collected. However, as had been necessary for the children’s first encounter with a data table, this representation also necessitated additional scaffolding. After failing to elicit any responses from her last question, her mediation took a new tack. She acknowledged out loud that “We have never seen this kind of graph.” Her use of the word “graph” here is interesting. Although this representation was not a standard “graph”
of any sort, I think Mrs. MacLean probably referred to it as a “graph” because it had more similarity with a graph than with a data table or diagram, which were representations familiar to the class. After thus giving the arrangement of data a name, she then asked the children to make explicit what physical phenomenon the tracings represented. In the following excerpt she evoked the experiences the class had had using Lesley’s notebook to aid Philip in thinking of the how to describe the multiple tracings of the can.

Mrs. MacLean: Well, I mean everybody had several tracings, is what I mean. There is not only one can... why did you have several... few... three, four? What do they mean? What do they tell us? If... if somebody who didn’t do this came in, what would they think about... why do we have several circles there?

Philip: Because that’s how far the ball, uh, hit the can.

Mrs. MacLean: Yeah, but why not only one? Everybody thinking.

Philip: Because every time the ball went in the same place.

Mrs. MacLean: Every time what did we do? What did we call that? What did Lesley call that?

Philip: Trials.

Mrs. MacLean: Trials. Thank you. So, these are the different trials, and we can see that it’s time we tried... we really never really went to the exact same place did we? So, the different trials, even though they didn’t go, uh, the exact same place, Sandra said about the same place.

One might consider the arrangement of the children’s data to be a histogram of sorts in that the intent seems to have been to draw attention to what extent the results of different groups were the same or different.
Mrs. MacLean then focused on one data set and asked the children to speculate about why a few green tracings were mixed with mostly red. This discussion allowed the children to remember more exactly what the procedure had been and what the tracings represented. The discussion elicited many ideas to account for the anomalous tracings. Among these were the ideas that the wrong crayon may have been accidentally used, that the pair of children collecting this particular set of data may have forgotten to change the number of blocks used, and that the data recording sheet or the can could have been placed incorrectly.

Having helped the children remember what exactly they had done to collect their data, Mrs. MacLean then reviewed the class’ *Claims About Motion* sheet and asked the children to think of the answer they would give to the question “does the height of the ramp make a difference in how far the ball will knock the can?” She also provided them with a sentence starter saying:

Mrs. MacLean... let’s start with low... “if the ramp is low”, uh, can someone continue?

Yes?

Child: It won’t go far.

Mrs. MacLean: What won’t go far?

Child: The... can, when the ball hits it.

Mrs. MacLean: O.K. (Writing on the Claims list) “If the ramp is low, it will not... the ball”, I’m sorry, “the ball will not move” (Child: The can far.) “the can”... and we say, very far? All right. That’s a beginning. Now somebody tell me another claim.

In this manner various members of the class went on to construct claims. By the end of the lesson, the claims for this day read:

- If the ramp is low the ball will not move the can very far.
- If the ramp is medium height, the ball will move the can a little bit farther.
• If the ball is higher, the ball can go faster and will hit the can farther.
• If the ramp is higher the ball will have more energy and have more momentum to go farther.
• The higher the ramp, the farther the can moves when it’s hit by the ball.
• The lower the ramp, the less the can goes.

In this description of the children’s encounter with representation something like a graph, I have illustrated how Mrs. MacLean cleverly engineered a data collection technique to facilitate using the children’s data to create a collective “graph.” I have also documented how, via a first-hand investigation, the class came to be able to use this representation to generate claims about the relationship between ramp height and momentum based on the data they had collected.

A few days later the class encountered a line graph in Lesley’s second big book on the final day of the unit of study (Day 10). Recall that in this book the problem centered around how to get a cake box to a waiting elephant by letting a clown car go down a ramp and hit the cake box. Lesley’s solution was to test whether changing the mass of the clown car (as represented by a ball) would change the energy or momentum that will be transferred to the cake box (thereby moving it all the way to the hungry elephant). In Lesley’s notebook, she had examined the question by testing how far a can would be hit by a 10g ball and a 100g ball. She then posed herself the task of interpolating to another ball that fell between the 10g ball and 100g ball. In this case she used a 50g ball. The children had been actively involved in making a prediction along with Lesley for the 50g ball. They had then been able to read her data table for her results with the 50g ball and compare her results to their own predictions. On the bottom half of page 12 (see Figure 8) was a line graph of same data about which Lesley had written “I made a graph that helped me see all the data together.” The balls were color coded with the lines and data points.
The children immediately recalled their own “graph” and suggested that Lesley must have copied them! Mrs. MacLean asked the class to think about what the data represented:

Child 1: She didn’t... we did the same thing that she did.

Mrs. MacLean: We did the same thing... except what’s the difference?

Child 2: She made dots.

Mrs. MacLean: No... no... no. What’s the difference between her data and our data?

What was she testing?

Child 3: The weight?

Mrs. MacLean: Raise your hand please this time. Yes, Ava?

Ava: The weight.

Mrs. MacLean: The weight. (pointing to the balls pictured on page 12) Gram... gram... gram. What were we testing?

Ava: The height.

Mrs. MacLean: The height.

Philip: No, how far it went.

Mrs. MacLean: Yeah, I mean, but we were testing the height of the ramp. She is... was testing the uh...

Philip: The weight.

Mrs. MacLean: The weight of the balls... if that would make a difference in how far the cans were going. So now, do you think mass or weight makes a difference in the momentum of something that’s going down the ramp?

Children: Hmm... Yes.

Child: Kind of.

Child: Yes.
Mrs. MacLean: O.K.

In this excerpt we can see two children’s different levels of understanding of the data. Ava was able to accurately compare the two line graphs the children had seen in terms of the variable that had been changed for each experiment. Philip may have at first been confused about how the same outcome measure (the distance the can moved) could be used to test two different relationships. However, in both children’s cases they had managed to interpret the line graph and understand key components of what it represented.

That most of the children had interpreted Lesley’s data to mean that a heavier ball would move the can further was exemplified by the suggestions the children made for how the clowns could change their circus act to get the cake to the elephant. Almost all of the suggestions involved adding weight to the clown cart in such inventive ways as adding bricks, putting 50 clowns in the cart, using heavier wheels, or having the elephant’s wife ride the cart! In addition, the notebook entries the children made on this final day of the unit of study demonstrate the children’s increased command of using data to support their conclusions about a scientific relationship. For example, Molly wrote:

*The weight makes a difference (difference). Because the bigger (bigger) the ball the more speed and momentum it has to give to the ball.*

Below this Molly drew a diagram showing a large ball and a small ball poised at the top of a ramp with cans at the bottom. Next to these diagrams was an “after” view of the same ramp, this time with the can positioned at a distance from the ramp of about 80cm for the big ball and at about 20cm for the small ball. (See Figure 12.)

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66 Interpreting Molly’s notebook entry is not completely straightforward. It is possible that Molly has simply written the last word of the second sentence “ball” when she meant to write “can,” or, as Mrs. MacLean suggested, Molly may have meant “it” to refer to the weight of the ball, so that her last sentence would mean “the bigger the ball the more speed and momentum the weight has to give to the ball.”
Sue who drew a similar diagram wrote:

Yes I theink (think) the weight mack’s (makes) a differins (difference) in how far an
obiect (object) that is hit moves. Because the bigger the the (sic.) obiect (object) is
the farther the can will go.

Jeffrey evoked the Big Book, writing,

The mass of the ball thats (that’s) hiting (hitting) a can makes a differnts (difference).
Because in the book it proved that. When a light ball is comeing (coming) down a
ramp it dos’nt (doesn’t) hit a can far. But when a hevey (heavy) ball is comeing
(coming) down a ramp it hits a can very far.

Finally, Sandra wrote the most complete notebook entry in which she compared the
results from the two different investigations that involved manipulating the mass of the
balls:

I think that weight onily (only) makes a differnt (difference) when you’re (you’re)
trying to hit something. If you are just leting (letting) a ball roll dowen (down) a
ramp then weight dose (does) not matter. Gravity will never change. And for the
first sentence (sentence) weight will make the ball stronger. The stronger the ball the
more power it has to hit the thing and give it power! The End.

Her entry also included a labeled diagram showing the distance a can would move if
hit by a heavy ball to be about 86cm, while the distance for a smaller ball would be about
19cm (see Figure 13).

These examples show some of the ways in which the children had learned to
communicate their ideas. In comparison to earlier notebook entries, there was more use
of technical terms such as “mass,” “speed,” and “momentum.” In addition, the specificity
with which diagrams were drawn in the children’s later notebook entries was markedly
improved. Among the eleven children who drew diagrams for their first notebook entry, only one child attempted to show some meaningful comparison about the relationship at issue and only 6 even labeled some component of their diagrams. In contrast, among the 19 entries for Day 10, all but one included a diagram. Eleven of the diagrams not only included extensive labeling (of the ramp, mass of the balls, starting points etc.) but were also arranged so as to allow for comparison across balls of different mass. Among the remaining seven entries, four had either no comparison or no labels at all, while three had a clear comparison but were not labeled in any way. In sum, there is evidence that children in the class could interpret graphical representations of data to address a question and that representations of their own thinking had in general become more focused and precise.

SUMMARY

In this chapter I have offered examples of how primary grade children were capable of experiencing fundamental aspects of scientific inquiry. In addition we have seen that it is possible to embed "science process skills" such as observing, predicting, and hypothesizing, which have traditionally been presented to elementary school children in isolated and reductionist ways (see Metz, in press), so that they are experienced in the service of advancing conceptual understanding. In the ten-day program of study, the children experienced: (a) making predictions, (b) evaluating data sets for anomalous data, (c) deciding when enough data had been collected, (d) figuring out how to record data, (e) discussing interpretations of data in terms of variables, (f) using data as the basis for generating scientific claims, (g) interpreting and comparing various representations of data, (h) scientific modeling of a phenomenon, and (i) designing and conducting a "fair test."

Of particular note, is, I think, evidence suggesting the importance of giving young children multiple chances to make links between recorded data from investigations and
the investigative procedures that resulted in those records. We have seen several times, in the case of the mass-speed data table and then again with the ramp-height – momentum investigation how the children were not able to make these links themselves, even when (in the case of the ramp-height – momentum investigation) the children themselves did the data collection. However, once the children either “reverse engineered” or were prompted to remember in detail how the data were collected, they were better able to interpret them.

Throughout this chapter I have provided some information about how the children were thinking about the science of motion in addition to descriptions of how they engaged in scientific inquiry processes. I thought this was necessary in order to for the reader to understand the children’s use of inquiry processes in context. In the next chapter, I focus more specifically on findings about the children’s ideas about motion, but as the reader will see, it will be necessary to sometimes describe the inquiry contexts in which these ideas arose. I will argue at the end of all this that “content” and “reasoning” are inextricably related and should, as much as possible, be allowed to coexist in early grade science curricula.