CHAPTER 5
DE-ACCELERATING: SLOWING DOWN TO DISCUSS THE TERRAIN TRAVERSED

Overview of the Chapter

In this final chapter, there are four major points for discussion. In the first major section, I examine three mediating factors of the instruction which were particularly salient: teacher mediation among the children, texts and tools, characteristics of the children’s behavior, and features of the notebook texts. This section is followed by one examining the links between scientific reasoning and content in inquiry-based science instruction. The third major point for discussion regards the role of meta-level processes in young children’s inquiry science experiences. In the final discussion section I examine some possible criticisms of the teaching and curriculum. Following these are sections discussing limitations of the study, implications of the study and directions for future research.

Three Factors Mediating Changes in Participation

From a sociocultural point of view, the children and Mrs. MacLean were engaged in a cultural enterprise (Cobb, Rogoff, Wertsch, Lave & Wenger). In their case one could call it inquiry-based school science. Some of the cultural norms of this enterprise were familiar to all the participants (e.g. taking turns to speak, raising one’s hand to get the
floor) and some were less familiar (e.g. interpreting a data table, using specific terminology to describe a particular relationship among variables). In the previous two chapters I have highlighted various aspects of the activities in which the class participated, as well as ways that participation changed or shifted (to varying degrees) over time. Many factors mediated these changes, and I have alluded to some of these throughout chapters 3 & 4. In this discussion, I characterize three of what were some of the most important of the factors mediating the instruction. These included (a) Mrs. MacLean’s decisions and moves, (b) the children’s ways of interacting and engaging with each other and each other’s ideas during the instruction, and (c) the tools, particularly the texts, used during the instruction. I will take each of these in turn, although in reality, these (and more\(^1\)) operated simultaneously in mutually constitutive ways.

**Teacher Mediation**

By teacher mediation, I mean the ways in which Mrs. MacLean helped the children make sense of the texts and intellectual and physical tools encountered in the investigation. There are a number of features of Mrs. MacLean’s teaching that are worth noting. First and foremost was Mrs. MacLean's deep respect for children’s ideas and her understanding of the way second-grade children might approach each of the questions the class investigated. She was careful to probe the children’s thinking until she felt she understood what each was trying to express. Of particular note is how she demanded clarification of vague referents (e.g. “it made it go faster”) in the children’s statements.

\(^1\) For example, some of the additional mediating factors one could have highlighted were the particular sociohistorical context of being in a semi-rural school in the Midwestern United States at the tail end of the
She also anticipated some of the difficulties her students might have with particular aspects of the Big Books and the first-hand investigations. For example, she expected that some of the children would have difficulty interpreting a larger number of seconds as meaning a slower speed. Therefore, before the program of study began, she led an exercise in which the children turned around in a circle during a certain number of seconds. I speculate that this activity allowed the children to have a visceral understanding of the notion of "seconds" that seemed to serve them well as I frequently observed children in the class being correctly interpreting the numbers of seconds in terms of relative amounts of time.

In a similar vein, Mrs. MacLean engaged the children in using gestures and pantomime during both first-hand and second-hand investigations. In the case of Big Book 1, Mrs. MacLean had the entire class literally act out the actions Lesley must have taken to collect her data. During a first-hand investigation Mrs. MacLean asked the children to hold up their fingers to predict how many seconds they thought the ball would take to reach the end of a ramp. She explained to the children that this way of predicting would allow all members of the class the chance to express their ideas at the same time.

It was not only the ideas presented in the text that Mrs. MacLean was skillful at mediating. Equally important were ideas that the children themselves brought to the investigation. In this regard, another aspect of Mrs. MacLean’s teaching that may have been particularly important for fostering an inquiry orientation to the investigations, was the way she strove to keep the discussion open to varying ideas. She had an array of ways of soliciting more ideas from the class, (e.g. Does anybody have a comment about 20th century, the affective climate and shifts over the course of the instruction, the power-dynamics among
that?, What do you think?, So, is there anyone who thinks that X, Y or Z?, Did anybody think differently? Any other predictions? Does anybody have a different idea?). Also striking was how she often asked for elaboration of “incorrect” ideas. For example, on Day 2, Joey was adamant that Lesley would have had both balls going down one ramp because that more closely resembled the sledding situation. Mrs. MacLean asked Joey to present his idea to the class and as he did she asked him to elaborate on several points. After he had done so, another child in the class suggested an alternative to Joey’s idea. Mrs. MacLean then asked this child to elaborate. Eventually, Mrs. MacLean was able to juxtapose these two ideas for the whole class and they became the grist for discussion (described in more detail in Chapter 4).

Indeed, there is evidence to suggest that a driving goal of Mrs. MacLean’s teaching was to keep the class conversation focused on the ideas at hand as well as on finding ways to make these ideas objects for reflection. One might think this would be the focus of all instruction, but all too often, science instruction can be turned into an exercise of following particular procedures in order to verify known outcomes (cite? does SAMPI have results like this? TIMS? Whitehead – inert knowledge?). We’ve already seen, in the example with Joey in Chapter 4, how Mrs. MacLean would take two children’s ideas and juxtapose them. In addition, by revoicing and sometimes elaborating on the ideas children expressed for the whole class she made the pace of the sharing ideas slower and more deliberate, thereby, perhaps, increasing the odds that each idea would be considered. She often asked children questions such as “how did you think of that?” which would demand children reflect on the process they used to arrive at an idea. The

the children, or the particular family profiles of all the children.
children asked questions like this were not always able to answer them, but in these various ways, Mrs. MacLean signaled that the children’s thinking was valued.

Mrs. MacLean also engaged in practices that conveyed the belief that the process of making sense of the investigations was an enterprise the class as a whole was embarked upon and to which each member of the class could/should contribute (cf. Scardamalia, Bereiter, & Lamon). This may be, at least in part, why Mrs. MacLean responded so strongly to Sarah’s comment about something her mother had said about the mass-speed investigation on Day 3 (described in Chapter 4). Of note for the current discussion is Mrs. MacLean’s statement: “I know that your mother said this and your mother said that, but we’re trying to be scientists.” Here she signaled to the class that the activity they were engaged in was ‘to be (like) scientists,’ and that it was an enterprise the class was embarked upon together. Also indicative of Mrs. MacLean’s strong emphasis on the importance of group discussion in the service of making sense of the investigations, was the way she introduced the first notebook text. She said, “I have a book that I would like to show you, that is a book on investigation about motion. … You and I are going to do some thinking with this book. We’ll think with it.” Now, one can imagine that she could have said “I have a book that has a scientist’s investigation about motion. We’ll read this book to find out all about what this scientist learned and how she did her investigation.” When one contrasts what she said, with what she could have said it is clear that her emphasis was on the process of understanding – a process that would depend upon the class doing some thinking with the book and with each other, rather than just from the book and on their own. Mrs. MacLean also stressed the class’ responsibility to one another to work together within the shared learning space. There were many instances of
Mrs. MacLean signaling this responsibility. In one interesting example from an excerpt already described in Chapter 4, Mrs. MacLean even implied that Lesley had an impoverished situation because she worked alone (“We are lucky we have a whole class. She didn’t have [that].”)

As much as Mrs. MacLean emphasized the collective, she also asked individual children to take a position and express their individual ideas about various situations. One could see this in the many opportunities she provided the class members to make predictions about various outcomes and also in the many opportunities she gave children to write about their thinking. Also important also was her stance that being unsure was a valid position to take. I found no instance of Mrs. MacLean criticizing a child for being uncertain about what they thought or why they had a particular idea. In addition to limiting her criticisms, she was also sparing in her use of praise. A compliment was usually reserved until after a particularly productive class discussion (e.g. after the class discussed the range of factors Lesley might change in the clown situation) or after a child had made an unprompted or especially complete statement about an idea (e.g. Sarah’s observation that the values in the mass-speed data table when added were the same).

Between validating the position of being uncertain, meting out praise, posing questions, elaborating on children’s contributions and orchestrating the smooth conduct of first-hand investigations, Mrs. MacLean controlled the flow of almost all of the class’ discourse. Each day she set the stage for the class’ work by reviewing the questions examined so far and the class’ claims and ideas about each question. In this way she both primed the children for the intellectual challenges of the new day as well as served as the class’ collective memory, reviewing with the class the history of their intellectual work.
Yet, within the structure she provided, the children had a good deal of autonomy. For example, there was a system for changing roles during first-hand investigations in which the children who had certain jobs would choose the next child to have that job\(^2\). I had the sense that this system was used often in many situations because of the total lack of discussion about it and because of the smoothness of the transitions as children took on new positions. This system is an example of a way Mrs. MacLean had imposed a certain structure which still allowed the children a good deal of choice and control. What was striking was the lack of bickering this system engendered. There was also the sense that the children were confident they would all get a chance to do something and say something – a sense that they were secure about their ideas and participation being valued. There were also segments of the instruction during which Mrs. MacLean ceded some control of the activity to the children. For example, during the class’ second replication of Lesley’s mass-speed investigation on Day 8, there were multiple difficulties with getting accurate times for the balls. For the first half of the data collection process, Mrs. MacLean kept a close and vocal watch on all aspects of the data collection process. However, by the end of that data collection activity, she provided these comments less and less, ceding the responsibility for ensuring that the tests were “fair” to the students (several of whom proved almost more scrupulous about the need for precision and accuracy than Mrs. MacLean had been).

\(^2\) Although she sometimes used the initial allocation of jobs as rewards for active and appropriate participation in discussions, Mrs. MacLean would often use another system (her sticks) to choose the initial children for various jobs. The sticks were popsicle sticks each with a child’s name written on it. They were put name-end down in a container, and Mrs. MacLean would use them as a way to randomly choose children (to call on or to do a job).
The writing activities were another time when Mrs. MacLean’s overall instructional system imposed a structure that maintained a large degree of choice and control for the students. During writing activity, the children were responsible for many decisions. For example, Mrs. MacLean rarely intervened when the children were choosing partners for writing, nor did she ever dictate a particular form the children’s writing should take. The children were responsible for deciding how they would express their ideas in their writing and illustrations.

Another characteristic of Mrs. MacLean's instruction was her flexible and creative use of the texts. The Big Books were not bound, allowing Mrs. MacLean to juxtapose pages on the board in any fashion she wished. In addition to having several pages up at the same time, she often either wrote on the laminated pages with a whiteboard marker, or attached additional sheets of paper to the books when she wanted to document the children's thinking in relation to the books' content. In addition, she created small posters of each of the guiding questions. She referred to these frequently during reviews of the investigations, as well as during the children's writing sessions.

The skill with which Mrs. MacLean used the texts and facilitated the investigations was, in part, a function of her careful planning. In addition to participating in all of the planning sessions that were a part of the GIsML community of practice professional development project (Palincsar et al., 1998), she also extensively tested the materials she was going to use. Her journal entries and lesson plans demonstrate how carefully she thought about what questions to ask the children at each point in the investigations. A final hallmark of her instruction - one that could not be planned for, was her opportunistic
use of children's comments (both written and oral) to introduce words and ideas or to raise questions and make observations.

Over the course of the instruction, I was surprised that it was rare for the children to ask questions of each other during whole-class discussion. It also seemed that the class discussions were dominated by a core group of children. Children outside this group were often encouraged to and did sometimes chime in, but there was a group of about 8 - 10 key players. Mitigating this to some degree, Mrs. MacLean also had ways to have all the children participate, such as during first-hand investigations and in making predictions of various outcomes, but during the discussion about interpreting the data there was less widespread participation. Perhaps, she might have been able to generate more widespread participation at the level of discussing empirical data by asking some of the less vocal children to justify their predictions.

If the reader has the impression of an extremely well prepared, thoughtful, engaged and responsive teacher, I have succeeded in my description of Mrs. MacLean. To summarize the various aspects of Mrs. MacLean’s teaching that were important in mediating the class’ motion investigations, I have created a table. The table is should be read across the columns, as I am suggesting that one can infer several key goals and beliefs from the practices which characterized Mrs. MacLean’s instruction.

<table>
<thead>
<tr>
<th>Beliefs</th>
<th>Goals</th>
<th>Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young children’s ideas are interesting and important.</td>
<td>Keeping the focus of class work on ideas (and open to varying ideas).</td>
<td>Probing thinking. Asking for clarification of ideas (e.g. referents). Using multiple modalities (e.g. gestures / pantomime, words &amp; illustrations in writing) Soliciting multiple viewpoints. Validating being uncertain.</td>
</tr>
</tbody>
</table>
Making thinking an object for reflection and discussion.

Juxtaposing ideas for discussion.
Labeling ideas
Literally posting ideas for consideration.

Establishing a learning community will reap intellectual and social benefits for the class. The having of and expressing of ideas in such a context can be highly rewarding to children.

Each individual to contribute to the collective enterprise.

Building from / Elaborating on children’s comments to seed ideas and pose new questions.
Revoicing ideas during class discussions for all to hear.
Sharing ideas expressed in children’s writing.
Extensive use of whole-class discussion around the interpretation of data.
Encouraging children to work in pairs during writing.
Sparing use of praise.
Sparing use of criticism.

Effective instruction demands careful planning and consideration of young children’s capacities.

Allowing the children a manageable degree of choice and control over their activity.

Establishing systems for routine activities (e.g. for changing roles during 1st-hand investigations).
Testing materials and procedures before the class used them.

Table XX. Characterization of Mrs. MacLean’s Instructional Practices, Goals and Beliefs.

**Peer Mediation**

The children’s role in creating a context conducive to thinking and learning really cannot be overstated, even though it was less obvious than Mrs. MacLean’s practices.

The most important way in which the children supported each other was that the children in Mrs. MacLean’s room, by and large, listened to one another. Besides giving the appearance of listening to one another during whole-group discussions, supporting evidence for this comes from the children's writing, where ideas (like Sarah's way of adding up the columns of numbers in the data table, and Aaron’s point that there had never been a tie) were appropriated by many children, not just by Sarah's or Aaron’s
writing partners. In addition to listening to each other, there is evidence that, at least some of the children, were actively trying to make sense of what one another said. Take for example, the following exchange from a point on Day 10 when the children were making predictions about what they thought would happen when a 50g ball hit a can at the bottom of a ramp. The page in Lesley’s notebook showed the data Lesley had collected for the distance a can had been hit by 10g and 100g balls. The values for the distance with the 10g ball were all around 20cm, and the values for the 100g ball were about 85cm. When it was her turn to make a prediction for a 50g ball, Sarah tried to explain how she decided to go about predicting a middle value for the 50g ball, but her explanation didn't really make sense until Aaron said that he thought he knew what she'd meant and explained it:

Sarah: My.. I know it.. because, uh, it’s 20 + 20 would = 40.. but, I mean like the 20’s and the 40’s and the 80’s..

Mrs. MacLean: So you’re counting by 20’s.

Sarah: So I think maybe we could, uh, I think maybe somewhere in the 40’s because then it would kind of be like.. uh, because.. 20’s..

Mrs. MacLean: O.K., is it a high 40 or a low 40? O.K., 20..

Sarah: And then there’s.. and then there’s 80 then you put 40 in the middle and it would be..

Mrs. MacLean: O.K., so somewhere in the 40’s you think? Is it a low 40 or a high 40?

Sarah: I think 44.

Mrs. MacLean: You think 44, all right. Uh, yes Aaron?

Aaron: I know what she was trying to say because half of 100 is 50 and half of 8 would 4 and half of 6 would be 3.

Mrs. MacLean: So, what is your prediction?
Aaron: It would be 43.

Mrs. MacLean: You think it’s 43. O.K., all right.

In this episode, Aaron was probably aided in figuring out what Sarah may have meant because his own line of reasoning about the problem was similar. He thought about the relationship between the 100g ball and the 50g ball (“half of 100 is 50”) and extrapolated from this to think that the distance the can would be moved by the 50g ball would be about half the distance it had been moved by the 100g ball. He happened to take just one of the values for the distance, 86cm, and so made his prediction of 43cm. But in this exchange Aaron also demonstrated that he had been listening to Sarah’s thoughts and was able to recognize the similarity to his own line of reasoning.

In addition to listening to and trying to make sense of one another’s ideas, the children supported the class’ activity by sharing their ideas and being willing to engage with the intellectual task. These are things one assumes will happen in classrooms, but if they do not occur, it would make the intellectual life of a class impoverished. Mrs. MacLean had doubtlessly been fostering particular ways of interacting with each other and with ideas from the very first moment of the very first day of the school year.

**The Texts as Mediating Factors**

Thinking of text as a “mediating factor” may seem odd at first – what does a text mediate? But when one thinks about how texts embody other people’s ideas and cultural values, a text can be thought of as mediating between the reader, the ideas, and the values (Karpov & Heywood, 1998). Written texts have been powerful tools for sharing ideas and values in societies for centuries (cite Olson, World on Paper; How the Irish Saved Civilization), yet the use of text in elementary science instruction is often regarded as an
inferior alternative to hands-on investigation (NRC, 1996). However, as this case illustrates, there are important ways in which text-based and materials-based experiences can work in concert to support children’s science learning. The Big Books provided a shared context for: (a) discussion of how a testable question can be derived from an observation of something intriguing in the world, (b) examination of multiple forms of representations of data as well as of experimental set-ups, (c) examination of a common data set with which to make knowledge claims, and (d) discussion of the reasoning another person (in this case, the fictitious Lesley Park) used while engaging in inquiry.

In addition, the Big Books were useful in supporting the children’s first-hand investigations. Recall in Chapter 3, for example, the challenge the students experienced when they encountered a data table for the first time in Big Book 1. Following this experience, when the class conducted their own first-hand investigation, a number of children spontaneously suggested recording their own data in a table. Certainly, Mrs. MacLean could have introduced the idea of using a data table in the course of a first-hand investigation. However, having the text-based encounter precede first-hand generation of a data table may have had several advantages. First, the amount of information provided in tabular form was limited; (i.e., the number of trials and the values of the data, though physically accurate, were kept limited for pedagogical reasons). When the children later replicated Lesley's experiment in their own first-hand investigations, they enthusiastically ran several dozen trials. Learning how to read a data table from such relatively large data sets would have likely made learning to read a table an extremely difficult task. Second, the data in Lesley's notebook were quite “clean.” In contrast, the data the children collected, though remarkably well done, were not as error free. Thus, examining their
own data sets for patterns was a much more challenging task because the children needed to deal with a greater range in the results, as well as more anomalous data. The challenge of this type of task is made all the more evident when noting the difficulty that the children first had in interpreting even Lesley's relatively straightforward tables. For example, they needed a great deal of help before they would accept "7 seconds" and "8 seconds" as basically the same result, given the accuracy of measurement. However, once the children had learned how to interpret Lesley's data and read tables, they were able to use data tables they generated themselves quite fluently.

There were several design features of the Big Books that were particularly salient to supporting the interplay of first-hand and second-hand investigations and affording children opportunities to advance their understandings of scientific concepts about motion and important aspects of scientific reasoning. What follows is a description of six design features that I propose to have been particularly generative in this program of study:

(1) *Multiple ways of representing data.* In the world of science, multiple types of representations are used to communicate ideas and experimental findings (Lemke, 1998). Likewise, in Lesley’s notebooks there were examples of several different types of representations, such as diagrams, graphs, and data tables. Recall for example, in both books there was a page with a diagram showing key components of Lesley’s experimental set-up. At other points in the books, data were represented in tables and graphs.

(2) *Use of norms and conventions of scientific community.* In general, scientists adhere to certain rules about conducting and reporting their research (Latour & Woolgar,
Using consistent and well-documented procedures in an experiment, and identifying the variables in a study and then controlling as much as possible for experimental errors, are just a few of the general norms and conventions of scientific communities for the conduct of experiments. The Big Books had opportunities for teachers and children to discuss several of these important aspects of scientific work. For example, in each book, Lesley posed questions to herself, examined the issue of what would be a “fair test” for each of her experiments, and carefully documented results from multiple trials.

(3) Use of narrative features and the presence of “voice.” The Big Books had a narrative quality to them to the extent that they were “stories” of Lesley’s investigations about the motion of balls down inclined planes. Lesley told her story in the first-person; she shared her thinking via her notebook and, in turn, was welcomed into the children’s classroom as another member of their learning community. For example, Sandra wrote “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 that the weight does not matter.” Sandra was not alone in explicitly disputing Lesley's thinking at various points. We suspect that the narrative quality of the texts enhanced their accessibility and facilitated the children’s skeptical stance.

(4) Examples of think-aloud expert reasoning. The Big Book texts had many moments in which Lesley models how a scientist might reason about a question or a problem. Recall that in Big Book 2, Lesley tested how far a heavy ball (100g) and a light ball (10g) will hit a can that is at the bottom of a ramp. She then used this information to make a prediction about a ball that weighed 50 grams. This use of extreme cases and
predicting for a case in the middle is one common way for scientists to explore a phenomenon (Teichmann, 1999). The inclusion of this situation in the Big Book allowed the entire class to participate in this kind of reasoning.

(5) Explicit reference to the source of questions. To model how a scientist may be motivated to explore a phenomenon, we designed the first pages of each Big Book to illustrate the circumstances that had piqued Lesley’s curiosity and led her to ask the questions that, in turn, drove her investigations. We did this, in part, to maximize the possibility that the class would discuss how to derive testable questions from observations in the physical world.

(6) Combinations of abstract and concrete representations. The Big Books included both schematic diagrams as well as pop-up book features. For example, Big Book 1, page 7 (see Figure 3a) included a set of transparency pages, which, when layered on top of each other, created a kind of time-lapse representation of a small, light ball and large, heavy ball going down a ramp. In Big Book 2, several pages included diagrams with pull-tabs to move one object toward or into another; (e.g., a can hit by a ball). In these examples there was a combination of a diagram of the situation – a more abstract representation than a photograph or movie – and a concrete demonstration of the action of the situation (e.g., movement over time, distance moved).

This list is not an exhaustive representation of the range of features that are possible in texts, nor does it include all of the features in the Big Book texts that were a part of this unit of study. Instead, these examples suggest features to look for in texts that can effectively support young children's scientific investigations and development of
scientific knowledge and reasoning. Indeed, it is to the major discussion point examining the relationship of scientific knowledge and reasoning that I turn next.

**Reasoning and Content are Inextricably Related**

A recurring theme throughout this dissertation has been how the ways of reasoning about data and/or how to conduct and investigation, were intertwined with shifts in the ways the children expressed their understandings of the data and scientific phenomena under investigation. For example, recall the discussion the class had about possible sources of error during Lesley’s investigation (described in Chapter 3), along with Sarah’s “epiphany” regarding the data table in Lesley’s first notebook (described in Chapter 4). These were pivotal events for many children being able to imagine that 7s and 8s could have been essentially the same amount of time, and therefore that the heavy and light ball might have actually been able to reach the bottom of the ramp in the same amount of time. In this example, we can see the combination of reasoning about experimental procedures and inherent sources of error, in combination with a new representation of the data contributing to a shift in thinking about a scientific relationship.

Indeed, across the study, we have seen how 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 described in this paper, 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."

This idea of scientific reasoning and content being linked is not new (e.g. [Bransford, 1990 #26], Chen & Klahr, 1999; Fay & Klahr, 1996; Millar). As Zuckerman et. al, in a review of research on scientific reasoning put it, "Scientific knowledge and the method of acquiring it are as inseparable as the movements of one's right and left legs when walking. However, the question of what leg to push off with become crucial when a child who does not know how to jump has to leap over the bar." (Zuckerman et al., 1998, p. 212) However, how to even have young children start their approach to the bar has rarely been discussed in regard to science curriculum design for primary-grade children (Metz, 1997). As Schauble has commented, “..one of the purposes for conducting experiments is to revise or extend existing knowledge; conversely, one's knowledge about the mechanisms and relevant concepts in a domain play an important role in guiding experimentation. This perspective implies that it may be misguided to try to teach students domain-independent experimentation processes or strategies. It also implies the converse: One cannot teach science as a set of declarative facts and concepts and expect students to emerge as skillful reasoners with their new knowledge." (p. 143) [Schauble, 1995 #55] The findings of this study suggest that more attention should be paid to creating curricula for primary grade children that integrate the use of scientific reasoning or “concepts of evidence” (Millar) processes within the pursuit of investigating a question involving interesting and important science concepts. In addition, of course, developers of such curricula need to take young children’s interests and strengths into account. Also important to consider, are issues pertaining to children’s developing
capacities to engage in meta-level processing of their experiences and ideas. I turn to this topic in the next section.

**The Role of Meta-Level Awareness**

The importance of metacognition in children’s academic learning has been recognized and discussed in various guises for about three decades [Borkowski, 1990 #183] and metacognition is considered “both a product and producer of cognitive development” (Paris & Winograd, 1990, p. 19). Deanna Kuhn’s work has been very important in drawing attention to the importance of meta-level processes during the consideration of evidence and theories when reasoning about evidence-based problems as in the case with scientific inquiry. As she has recently written, “awareness of the sources of one’s knowledge is critical to understanding evidence as distinct from and bearing on theories – an understanding that lies at the heart of scientific thinking” [Kuhn, 2000 #177, p. 178]. With precursors manifested in such milestones as expressing an understanding that people have their own thoughts and that one’s own thoughts may vary from those of others (theory of mind) (Wellman), Kuhn suggests that metacognitive and metastrategic awareness and control develops over a lifetime, often never being fully realized in all content domains (Kuhn, 1989, 1997, 2000).

That young children have difficulty with meta-level awareness, such as distinguishing between an assertion and the evidence supporting that assertion is well documented as is the finding that young children also have difficulty articulating how they have come to know something [e.g. Kuhn, 1999 #176; Flavell, 1999 #178]. The children in Mrs. MacLean’s class also manifested some difficulties with these issues. This could be seen in some of the children’s writing when their “explanation” of their thinking was that, for
example, mass affects speed because ‘it just does.’ In addition there was one noteworthy moment related to the issue of knowing how one has come to know something during a class discussion. This episode, which occurred on Day 9, began when Mrs. MacLean asked Ethan how he had learned that changing the height of a ramp would affect the amount of energy that could be given to a can (described in Chapter 4). He answered that he had learned it “from the other book” to which Mrs. MacLean was incredulous, responding that she had not seen that idea in any book. She then asked the rest of the class where they had learned about ramp height affecting the amount of energy a ball would have to give something at the bottom. Another child, Travis, repeated Ethan’s statement that it had been in Lesley’s other book, and then the following exchanges occurred:

Mrs. MacLean: Who agrees with Travis? Where did we learn that then? If you don’t agree with him. Andrea?

Andrea: On that piece of paper. [referring to the class claims list that was posted on the board]

Mrs. MacLean: The piece of paper. Well, what happened, this piece, where did we get the ideas for the.. for the piece of paper? .. Aaron?

Aaron: We thought of it.

Mrs. MacLean: Yes, we thought those. But when, after what? Yes, Joey?

Joey: We learned it from me.

Children: [laugh]

Mrs. MacLean: What did we do to learn that? Matthew?

Matthew: We did the ramp.

Mrs. MacLean: We did the ramps.
Child: We tried them.

Mrs. MacLean: We tried them and that’s how we got all these claims. when we tried those that’s what they did. That’s what those balls did. That’s what those ramps did. O.K. So that’s why Ethan learned that. It’s amazing how things get into your head. you don’t remember how you learned them, isn’t it?

In this excerpt we see Mrs. MacLean adamant that the class would re-construct how the idea about ramp-height and energy had been derived. This was just one of many instances when Mrs. MacLean emphasized the distinction between what were ideas on the basis of Lesley’s data and what were ideas based on data the class had collected. At other points in this dissertation, I have discussed how Mrs. MacLean made opportunities to juxtaposed various ideas, in a sense making them objects for reflection. And, we have also seen children working at contrasting their own thinking with that of their peers and with the ideas in Lesley’s notebooks. In addition, we have seen children identify when they were uncertain about something. This awareness, which seemed more than just a ploy for dodging a question, could be a critical component of metaconceptual awareness.

This study was not designed to assess to what degree such actions on Mrs. MacLean’s part might have aided some children in acquiring and perhaps articulating an awareness of how they had come various claims. Nor would the data have allowed for making a trace of individual children’s meta-level awareness. However, this study does raise questions about how young children’s awareness of their own thinking might be

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3 My favorite of these was on Day 4 when the class switched from examining Lesley’s first notebook, to examining the relationship between ramp-height and speed. Mrs. MacLean remarked “It’s not Lesley anymore, it’s us,” and Joey, always quick on the uptake, responded “It’s Usley!”
heightened during inquiry-science instruction. An interesting line of research could be to examine what might result from sustained metacognitive (reflective) activity being integrated into regular science instruction, informed by attempts to do this with older students [e.g. Hogan, 1999 #54; White, 1998 #83]. Important in such research would be to pay attention to how the social context and perhaps additional tools may be utilized to share some of the burden for reflective thinking about experimentation and how evidence and knowledge claims are related.

**Critiques of the Curriculum and the Instruction**

I would like to make clear that, although I would claim the curriculum and instruction were efficacious as evidenced by the levels of engagement and often sophisticated thinking exhibited by children in Mrs. MacLean’s class, this study was not designed to evaluate the relative merits of various possible ways of teaching this unit of study. However, in this discussion, the curriculum and instruction described in this dissertation deserve some critical attention.

For example, readers may have questioned Mrs. MacLean’s choice to emphasize terms such as momentum, energy, and mass. Though not addressed head-on in this paper, the issue of choosing what words to use in science instruction is, of course, an ever-present concern. This study was not designed to evaluate the impact that particular language choices may have had (although this issue is one ripe for additional research). However, it is the case that given the sociocultural perspective with which this work was undertaken, words can be thought of as tools, and their use as indicative of children’s appropriation of those tools (Wertsch, 1991). Appropriation however does not imply mastery, and indeed, I would expect that the children’s understandings of these
words/tools would be incomplete after this unit of study. In my view this is as it should be, as over time, and repeated opportunities to think about and use these words/tools in varied contexts, the children’s understandings will become more elaborated.

In the section of the paper about children’s use of multiple forms of representations (in Chapter 3), readers may be concerned about the use of a non-standard “graph.” I am aware that within science education research, there has been a great deal of conversation and concern about what sense children make of graphical displays. Much of this research has been about representations that have come from a “black box” – such as graphs generated by handheld microcomputers (e.g., Mokros & Tinker, 1987). I agree that it is important to be extremely thoughtful about the representations used with children, but I speculate that even non-standard representations, may be useful intermediaries (another possible research agenda). In the case of the compiled student data, a class-generated representation which, though not a canonical graph, looks a bit like a graph, I observed many of the children using this representation to make sense of the data they collected. In addition, it appeared to have helped at least some of them (certainly Ava) subsequently make sense of the graphical representation in Lesley’s notebook. That such young children were observed to be actively engaged in trying to understand quite complicated, and one might even say abstract, representations is, in itself, an important finding. That young children made use of graphical representations, whether or not they understood all aspects of and subtleties of those representations, in the service of addressing a question, is very exciting. I trust that the children who participated in this unit of study on motion will have more opportunities to refine their understanding of graphs and other forms of representing data as they go through school and into their adult lives. The episodes
described in this study raise tantalizing questions about the range of representations young children may be able to use and about how to scaffold this use.

**Limitations of the Study**

The most obvious limitation of this study is that it is a study of just one case of just one class and one teacher. A case, by its very nature of being a case of something, must have some characteristics of a more general category of experience. Yet a case is also unique, and thus there are limitations regarding the extent to which general principles can be inferred from one case. As Janesick has put it, “Every instance of a case or process bears the stamp of the general class or phenomena it belongs to. However, any given instance is likely to be particular and unique. Thus, for example, any given classroom is like all classrooms, but no two classrooms are the same” (p. 201). The case of Mrs. MacLean’s 2nd grade class studying about the motion of balls down inclined planes is a case of young children engaged in scientific inquiry. Some aspects of this case could be called “typical”: for example, many 2nd grade classes in semi-rural American schools are similar to Mrs. MacLean’s in terms of class size and the children’s backgrounds. However, as a teacher Mrs. MacLean has many particular and unique qualities. Personally, she is unusual in her strong interest in science and her many years of thinking about how to, as she puts it, “foster a habit of inquiry.” Also important was that she was given a great deal of support by a research team and was using materials especially designed for the unit of study and grade level by that research team to whom she had daily access. This fact limits my ability to say that the results of this study could be readily replicated. In addition, I have only chronicled one enactment of the unit of study.
and cannot therefore comment on whether the outcomes would be different with another
group of students.

There were also several methodological limitations. The data for this study were not
collected for my particular set of question and as my analyses progressed, I became
aware of ways in which the data, though very rich, could have been even richer. I would
have liked to have some interview data with the children at various point in the
instruction, as well as to have had several additional questions on the pre-/post-
assessment. In addition, when collecting these data, I did not realize how important the
children’s writing activity would turn out to be. Thus, there were two days of writing
activity that were not videotaped. I very much regret not having access to those data.
The issue of relying on video data also its drawbacks as well, in that the view of the
camera is inescapably limited [Baker, 1997 #180]. The camera generally followed Mrs.
MacLean and I therefore could not always ascertain exactly which child made certain
contributions at various points. To the extent that I could identify children by voice
(when their faces were in the camera’s view), I have done so. The use of only one
camera also meant that during small group work (e.g. data collection for the ramp-height
– momentum investigation & writing activity) data were only collected for the
interactions in which Mrs. MacLean participated. Thus, I did not have access to any
information about the nature of talk among the children when by themselves. This has
limited by ability to comment on the children’s more independent capacities to engage
with the ideas and conceptual tools at play during the instruction. Were I to collect these
data again, I would video record at least one small group in addition to maintaining a
video-record of Mrs. MacLean’s interactions with children during small group work.
Then, of course, there are by own biases which have no doubt limited my ability to see various aspects of the data, however hard I have tried to be thorough and careful. My belief in young children’s tremendous potential to bring to bear all the resources at their disposal to a task they find engaging, has probably had the greatest impact on this study. This does not mean that I deny that their resources have limitations, and are undergoing development, but I do admit to thinking that, in general, my own limitations to discern how children are thinking about phenomena may well be greater than the children’s limitations in thinking about them.

**Implications of this research**

In the introduction to this dissertation, I argued that, among the factors conceivably limiting the opportunities young children have to experience inquiry-based science instruction, there are too few illustrative cases of what young children are capable of when supported by a knowledgeable teacher, in a social context in which they collaborate with others, and when they are provided access to tools (such as notebook texts) that are useful to advancing both conceptual understanding and the capacity to engage in scientific reasoning. Given this argument, I believe the following implications from this interpretive case are particularly relevant.

The first implication is that primary grade children are capable of experiencing fundamental aspects of scientific inquiry. This has ramifications for the design of curricula. Even the best of the currently available curricula for primary grades often has as its basis an engineering approach to science lessons (e.g. STC, FOSS). Many lessons in these curricula are structured so as to pose a design challenge to the students leading to a corresponding emphasis on manipulating variables in order to make things happen. We
have seen in this case study that young children are capable of going beyond such an approach\(^4\). They were engaged in thinking about relationships involving some of the biggest of the ‘big ideas’ in science for the sake of trying to answer questions that involved these concepts. They interpreted real data and made claims based on those data. This was the stuff of scientific inquiry. Yet, let me reassure the engineers of the world: I am not advocating for getting rid of other types of science experiences in elementary school. Engineering problems are motivating, and intriguing and young children will benefit from engaging with them, but I maintain that even basic questions about phenomena can be within the grasp of primary grade children and that these inquiry experiences should also be pursued even in children’s first years of school. What is called for is a varied and balanced intellectual diet.

The second implication is that teacher mediation plays a powerful role in supporting children’s learning in inquiry-based instruction. Thus, how early elementary grade pre-service teachers and practicing teachers are supported in learning to teach science deserves a great deal of attention. Although I would not want all teachers to be carbon copies of Mrs. MacLean, there is much to learn from her practices. Studying cases such as hers should be an integral part of elementary science methods courses.

The third implication is that properly designed texts have a significant role to play in advancing young children’s conceptual understanding and scientific reasoning. Concerns about how to teach young children to read and write dominate the agenda for teachers at this grade level, and this will not change any time soon. Yet, there seems to be a growing consensus that children and their teachers are greatly disadvantaged when denied rich

\(^4\) Although one could consider the circus context a “design problem” with the goal of solving a problem.
subject matter information with which children might read, write, and think (Neuman, Taylor, Pearson, Clark, and Walpole, 1999). Unfortunately, primary grade classrooms often have an impoverished access to informational text of any sort (Duke, 2000), let alone books about science written expressly for children in these grades. Clearly, a written text is only one source of knowledge, but nevertheless, it is potentially a rich source of knowledge. For example, the research of Anderson, Wilson, and Fielding (1988) and Cunningham and Stanovich (1998) reveals that exposure to print is highly predictive of vocabulary development, verbal fluency, and subject matter knowledge.

The fourth implication of this study is that there are many issues still ripe for additional research, and it is to these that I turn next.

**Directions for Future Research**

Despite the fact that this is a case of just one class and an excellent teacher, the results reported in this dissertation raise important questions for further research. For example, more research is needed to determine the types of topics and range of investigative activity in which young children develop scientific literacy. If we are going to be able to help teachers strive toward fostering high levels of engagement in science, especially for young children, we need more information about how children’s capabilities develop in the complexity of classroom settings.

Another set of questions concerns the value of inquiry-based instruction. Aside from a number of studies that were conducted 30 years ago (e.g., Shymansky, Kyle & Alport, 1983; Shymansky, Hedges & Woodworth, 1990) to look at the effects of the inquiry-based curricula developed in the 60s, and meta analyses in the early 80s that sought to generalize across those studies (Anderson, 1983), there has not been concentrated effort
to study teaching and learning in inquiry-based instruction. Many elements that may be
critical to making inquiry-based instruction productive have been described in this study,
but additional research could examine to what extent different teaching practices are
necessary for effective instruction with young children.

All instruction is situated within a learning environment, and it is clear that the
attributes of Mrs. MacLean’s teaching, which engendered a strong learning community,
were critical to the effectiveness of her instruction. This suggests another avenue for
future research. How do teachers establish such an environment, especially with such
young children for whom schooling is a novel cultural experience? Having cases of the
genesis of learning communities in classrooms may be critical to helping many teachers
move to the next level of effectiveness in their instruction, regardless of whether it is
inquiry-based. Moreover, underlying such research is the issue of how a teacher develops
the type of expertise exhibited by Mrs. MacLean. Studies of this type could use a
longitudinal design and take advantage of professional development programs such as the
GIsML Community of Practice of which Mrs. MacLean was a part.

Although some ways in which the children were engaged in inquiry processes have
been featured in this study, some of the challenges they faced have also been described.
There are multiple avenues for additional research among these challenges. For example,
issues such as the number of critical variables to investigate in a given context, and the
extent to which variables of interest are measurable (like the distance a can moves) or
require calculations (like speed, from distance and time measurements), make a
considerable difference in the degree of challenge in investigative contexts. One way to
address these issues with young children is to set up direct comparisons rather than
having the children measure. What are the affordances and constraints of curricular
decisions of this sort? Do we find substantial learning advantages, or are children’s
opportunities to reason about a situation unnecessarily limited? These are important
questions for research.

Finally, the results of this study suggest an even greater need to specifically examine
children’s learning from text in science, especially with different forms of text. In the

case of texts that are designed as a scientist’s notebook, there are basic questions about
what these tools are most suited to do, and how they can be most powerfully used. What
are the best aspects for notebook texts to model in relation to first-hand investigation?
What structure and format of notebook texts are optimal? Would children benefit more
from several excerpts of a few pages that fit together like several short stories that are
interrelated, or from longer excerpts that more explicitly tell the story? In addition, it may
be that different topics and investigative contexts require different decisions about what
ideas to highlight. What are some of the principles we can use to guide these kinds of
decisions?

**FINAL THOUGHTS AT THE END OF THE JOURNEY**

Science curriculum reform documents in the United States call for children to engage
with “big ideas” which include the big ideas of how to conduct systematic investigations
and make claims about observations of phenomena in the world as well as justify those
claims with evidence (American Academy of Sciences, 1993; National Research Council,
1996). The idea that such activity, in some authentic form, is too advanced for young
children can be dismissed. How to engage in such activity will be an on-going concern,
one that will necessitate a range of approaches. Asking children to generate their own
“wonderful” questions will always be an important way to engage children in thinking about their worlds. Yet, formulating a generative question is no easy task. Thus, as exemplified in the pages of this dissertation, valuable learning opportunities can result from asking children to ponder very specific discipline-based questions. Such questions, and the ways of approaching such questions within particular disciplines, can offer children opportunities to try out, and succeed at many ways of experiencing the world, including among them scientific inquiry.