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Mrs. Miller's Evolution in Teaching Science as Inquiry: A Case Study of a Teacher's Change in Responsiveness

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by

Jennifer Evarts Lineback

Committee in charge:

University of California, San Diego

Professor Jeff Rabin
Professor Gabriele Weinhausen

San Diego State University

Professor Fred Goldberg, Chair
Professor Meredith Houle-Vaughn
Professor Jessica Pierson

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The Dissertation of Jennifer Evarts Lineback is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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University of California, San Diego

San Diego State University

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DEDICATION

This dissertation is dedicated to my husband, Todd, who never doubted for a minute that I was capable of achieving this and our daughter, Sedona Elizabeth, whose unconditional love and boundless joy continuously lifted me up.

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VITA

1995	Bachelor of Arts, Chemistry Bachelor of Science, Zoology Miami University, Oxford, Ohio
1995-1997	Teaching Assistant, Zoology Miami University, Oxford, Ohio
1997	Master of Science, Zoology Miami University, Oxford, Ohio
1997-1998	Teacher, Biology Miss Porters School, Farmington, Connecticut
1998-2001	Teacher, Biology, Life Science, Physical Science Palmer Trinity School, Miami, Florida
1999-2001	Adjunct Professor, Biology Miami Dade Community College, Miami, Florida
2001-2005	Teacher, Biology Landon School, Bethesda, Maryland
2002-2005	Presenter, Biology Curricular Supplements Office of Science Education – NIH, Bethesda, Maryland
2003	Teacher, Biology Center for Talented Youth, Johns Hopkins University (Lancaster, PA site)
2005-2007	Teacher, Biology, Environmental Science International School of Port of Spain, Trinidad and Tobago
2007-2008	Research Associate, San Diego State University San Diego State University, San Diego, California
2008-2011	Research Associate, San Diego State University Research Foundation San Diego State University, San Diego, California
2011-2012	Adjunct Professor, Biology Point Loma Nazarene University, San Diego, California
2012	Doctor of Philosophy, Mathematics and Science Education University of California, San Diego, San Diego, California San Diego State University, San Diego, California

ABSTRACT OF THE DISSERTATION

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by

Jennifer Evarts Lineback

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San Diego State University, 2012

Professor Fred Goldberg, Chair

Calls for reform-based science instruction have highlighted *inquiry* as a critical component in science education (e.g. National Research Council [NRC], 1996, 2000, 2007). To date, there has been little research describing *how* teachers' classroom practice changes as they implement inquiry-based instruction. This study characterizes how an experienced elementary school teacher changed with respect to her *responsiveness to* *student thinking* (i.e. the degree to which she followed up on her students' ideas) as she implemented three iterations of an inquiry-based module on the water cycle.

This research was guided by two overarching questions: (1) How can a teacher's responsiveness to student thinking be characterized?; and (2) How does one teacher, Mrs. Miller, change with respect to her responsiveness to her students' thinking over the course of three iterations of an inquiry-based module? In order to answer these questions, two distinct, yet complementary, methods of analysis were used.

Method 1: Discourse analysis of classroom dialogue led to the operationalization of the "redirection." Redirections are teacher bids to "redirect" students' attention from one locus to another and reflect differing degrees of responsiveness, according to the degree to which the teacher takes up students' ideas. Initial quantitative analyses of Mrs. Miller's redirections showed that while she *did* change in her responsiveness to student thinking, the change was not linear. When Mrs. Miller's *highly responsive* redirections were analyzed, however, she seemed more likely to use highly responsive redirections to perpetuate students' potentially productive ideas during Implementation 2 and especially during Implementation 3. Such results suggested that Mrs. Miller *grew* in responsiveness over time.

Method 2: Phenomenological analyses of Mrs. Miller's practice provided further support of her increased responsiveness to student thinking. Mrs. Miller seemed more willing to encourage students' consideration and elaboration of "alternative" explanations during Implementations 2 and 3. Additionally, she appeared more likely to allow student ideas to inform future discussions during later implementations.

This research provides the educational community with a detailed description of a veteran teacher's change in responsiveness during inquiry instruction and establishes a foundation from which others interested in teacher change and/or promoting reform-based instruction can build.

CHAPTER 1: RATIONALE

"Inquiry is central to science learning" (National Research Council, 1996, p. 2).

"Inquiry instruction is the preferred mode of science instruction for students in all grades from kindergarten through graduate school" (Lawson, 2010, p. 97).

1.1 Introduction

What happens to a teacher's practice as he or she transitions to teaching science as inquiry? Implementing new methods of science instruction, like any novel pedagogy, takes time and effort on the part of the teacher and often requires considerable support along the way (Guskey, 1985; Lappan, 1997; National Research Council [NRC], 2007; Schwartz, 2009; Wee, Shepardson, Fast, & Harbor, 2007). Unfortunately, little is currently known regarding how inquiry instructional practices develop over time (Schwarz, 2009; Thompson, Braaton, & Windschitl, 2009). In order to more effectively train teachers to promote scientific inquiry in their classrooms, it is imperative that researchers understand how practitioners evolve in their practice with respect to inquiry teaching.

Few educational researchers have focused their attention on veteran teachers' practice *in situ* as they endeavor to adopt reform-based instruction. As such, the educational research community would benefit from in-depth case studies that track teachers' instructional practice over time as they implement new pedagogies. Such studies could result in rich characterizations of teacher strategies and behaviors and potentially provide the field with strong foundations from which to generate new professional experiences for both in-service and pre-service teachers.

In this document, I provide such a case study. I describe an in-depth analysis of a single experienced teacher, Mrs. Miller, as she implemented inquiry-based science instruction over three years. As part of this description, I characterize a new construct, the "redirection," which affords researchers a means by which to analyze an important aspect of a teacher's practice: responsiveness to student ideas. I then use this construct to analyze Mrs. Miller's practice across three implementations of an inquiry-based module on the water cycle, resulting in a rich description of her change in practice. Finally, I expand my examination of Mrs. Miller's practice beyond her use of redirections by adopting a phenomenological approach to data analysis. This extension culminates in an even more comprehensive story of how Mrs. Miller changed with respect to her responsiveness to her students' thinking.

In the remaining sections in chapter 1, I describe an overview of the research study and discuss how the findings contribute to the larger educational research community. In chapter 2, I review the relevant literature that informed and situated the study, and in chapter 3, I elaborate and exemplify the research design of the study. In chapters 4 and 5, I present and exemplify the redirection methodological construct and use it to analyze Mrs. Miller's practice during three iterations of the water cycle module. In chapter 6, I extend these analyses by broadening the lens by which I examine Mrs. Miller's practice, generating a more holistic picture of her change. The final chapter consists of general conclusions, implications, and limitations of this research, as well as suggestions for future extensions of the work. I now turn to a brief description of scientific inquiry and its current emphasis in science teaching and learning, which provides the underlying motivation for this study.

1.2 In the pursuit of inquiry

Science education in the 21^{st} century has maintained a strong focus on inquiry in the classroom. Science standards at both state and national levels have emphasized its importance in the primary and secondary grades (e.g. California Department of Education, 2000; NRC, 1996, 2000, 2007). Teachers are pressed to incorporate scientific inquiry practices into their science instruction, in order to help their students reach inquiry-based learning outcomes (American Association for the Advancement of Sciences [AAAS],1989, 1993; NRC 1996, 2000, 2007).

Unfortunately, there continues to be ambiguity among those in the educational community as to what is entailed in teaching for scientific inquiry (Bybee, 2000; French, 2005; NRC 2006; Tang, Coffey, Levin, & Hammer, 2008; Wee, et al., 2007). As Llewllyn stated, “Ask a roomful of science teachers to explain the meaning of inquiry, and you will probably get a roomful of different answers” (2002, as quoted in French, 2005). There does seem, however, to be consensus as to what the end-result of inquiry instruction should be: students should develop *knowledge of and an appreciation for* scientific practices, as well as *experience in* those practices (Bybee, 2006; NRC, 1996; 2000, 2006, 2007). A great part of scientific inquiry pedagogy, therefore, should center on engaging students in practices consistent with those in which scientists engage (Justice, Rice, Warry, Inglis, Miller, & Sammon, 2007; NRC, 2000, 2006, 2007; AAAS, 1989). Such instruction should include opportunities for observing and reasoning about phenomena, posing questions about and generating possible hypotheses and explanatory models for phenomena, considering alternative explanations, proposing and carrying out investigations to test possible explanations, and evaluating and communicating about the outcomes of those investigations (Harwood, 2004; Lawson, 2010; NRC 1996, 2000; Sandoval, 2003; Tang et al., 2008; Windschitl & Buttemer, 2000).

For many practitioners, the implementation of such reform pedagogy is met with anxiety and confusion (Bybee, 2000; French, 2005; Wee et al., 2007). This is primarily due to the fact that such instruction differs from that which the teachers have traditionally practiced and/or experienced as learners themselves (Tilgner, 1990; Wee et al., 2007; Windschitl, Thompson, & Braaton, 2008). Studies have shown that many teachers rely on teaching the scientific method, with its straightforward list of steps, as their primary means of inquiry instruction (Tang et al., 2008; Wee et al., 2007; Windschitl, et al., 2008). However, such a prescribed method is only a simplified model for the process of inquiry; scientists take one of any number of pathways when engaging in the scientific endeavor (AAAS, 1989; Bybee, 2006; Finley & Pocoví, 2000; Harwood, 2004; McComas, 1996; NRC, 2000; Park, Jang, & Kim, 2009; Windschitl & Buttemer, 2000). Teaching inquiry as a single list of ordered steps to be followed is not enough to encourage a deep understanding and appreciation for the scientific enterprise (AAAS, 1989; Bybee, 2000; NRC 2000; Tang et al., 2008). Furthermore, equating “scientific inquiry” with the “scientific method” may constrain how students engage in the practices of science and downplay the importance of creativity (Lawson, 2010; Tang et al., 2008) and flexibility (Windschitl & Buttemer, 2000) in the scientific process.

The Learning Progressions for Scientific Inquiry project[1], the larger professional development and research project from which this case study emerged, represents one of several nationally funded efforts to encourage and promote teachers' ability to teach inquiry. Each of these projects necessarily maintains its own perspective on what inquiry is and how teachers can effectively teach it. The Learning Progressions (LP) project's team has adopted the definition of scientific inquiry proposed by Hammer, Russ, Mikeska, and Scherr (2008), who characterized inquiry as "the pursuit of coherent, mechanistic accounts of phenomena" (p. 150). This definition seems to be consistent with the scientific enterprise, in that the *pursuit* is not simply considered to be the means to an end, but an end in and of itself (Sikorski & Winters, 2009). Scientific inquiry is cast as a sense-making endeavor, one where students (and teachers) reason about and develop plausible explanations for natural phenomena. According to this perspective, the focus of student inquiry-based activities should be the consideration of natural phenomena, rather than the achievement of specific content objectives.

In order to promote this kind of inquiry, the LP project staff has developed curricular modules that provide a context for teachers to engage their students in this sense-making process. These LP curricula are in contrast to those that dictate specific content elements to which students are to be held accountable. The modules represent *responsive* curricula[2]; they contain no prescribed learning agenda nor prepackaged lesson plans. Instead, the modules allow room for student ideas to emerge via discussion and provide space for teachers to be responsive to those ideas in the moment. As student observations and explanations arise via the consideration of natural phenomena, the teachers are afforded the flexibility to pursue their students' ideas, allowing them to be extended, elaborated, and exemplified.

1.3 Meeting Mrs. Miller

This case study is centered on one of the fifth-grade LP teachers, Mrs. Miller[3], as she implemented one of these inquiry-based curricular modules (i.e. the water cycle module) in three successive academic years. With more than two decades of teaching under her belt, Mrs. Miller had a wealth of experience teaching science. This instruction had historically been, according to Mrs. Miller, primarily content driven and grounded in heavily guided activities that moved the students through the "traditional" steps of the scientific method[4]. The water cycle module she implemented as part of the LP project differed dramatically from the curricular materials she had used previously. As described above, the module's format was much less focused on moving students toward specific content goals and more on creating space for students to reason about, generate explanations for, and test hypotheses regarding natural phenomena. Thus, this curriculum provided an excellent opportunity for Mrs. Miller to modify her inquiry instructional practice.

The following piece of transcript was taken from a class session early in Mrs. Miller's first implementation of the water cycle module. It provides one example of how Mrs. Miller engaged with her students within this type of open and flexible curriculum. The immediate context for this excerpt is a discussion concerning the different appearances of clouds.

Transcript 1.3a [1.2.20:05 - *italics* indicates emphasis by the speaker]

Mrs. Miller: Alright, again, one more time, location. Other than in the air, so, high up? Low to the ground? We had talked about fog being low to the ground. Well, is there a connection between where the clouds are located and what they look like? Cam?

Cam: Well, I think they're kind of like a little bit, like, there're a little closer to, like, to the earth than space. Like, space would be hi- further, yeah, like a lot of- further than the clouds are to the ground. So, it's- they're probably like- space is probably three fourth above and the earth is probably one fourth below.

Mrs. Miller: O-Kaaayyy. So- so- Tommy?

Tommy: I was thinking that, when you're at the, like the, um, ocean? To the west, in early- you get dark clouds. Usually, it would be marine layer, and it- um, most of it would be moving *in*, and then when it gets *in* enough, it will just come into a *cloud*. I don't know-

Mrs. Miller: But, ah- wh- are they high or low? What's the altitude, I guess is what I'm asking, what's the altitude of the clouds?

Tommy: Well, when they're by the ocean, they're gonna be low. And then, when- when they're going on land, they're just going to drift a little higher and higher.

Mrs. Miller: 'K, so they're gonna get *higher*. Is there someway we can connect how high they are with what they *look* like?

Jack: Ah, maybe they look different from different heights?

Mrs. Miller: Can *you* give an example? (10 sec pause) Who can help him? Who can help him out? Jack made- he made a good comment… He said …Maybe, clouds look different at different heights. So, what does that mean? Cam?

Cam: Maybe when, like, there's storm rainy clouds, way high, maybe that means it just gonna drizzle or something. But, when they're lower…it's gonna like pour and rain really hard.

Mrs. Miller: (writes on the board) "Lower. Clouds. Heavy rain. Higher clouds. Drizzle." What does anyone else think about that? About clouds and their altitude as to how they look…?

After a few more students describe different types of clouds they've seen, Mrs. Miller asks the class to organize the various kinds of clouds they've described into categories and, later, rank the categories in terms of altitude. The remainder of the class session is spent with Mrs. Miller guiding her students to collectively characterize the connection between different kinds of clouds and weather.

Compare Mrs. Miller's interactions with her students in the above segment with those in Transcript 1.3b shown below. It was taken from a class session during Mrs. Miller's second implementation of the water cycle module. The context for this particular segment is, once again, clouds. However, this time the discussion centers on a possible connection between the evaporation of water and the formation of clouds. For brevity, a portion in the middle of the segment has been left out.

Transcript 1.3b [2.2.08:04 – *italics* indicates emphasis by the speaker]

Mrs. Miller: O- Kay. Martin?

Martin: … Once when I was out in the desert, I looked up in the sky into the light. There'd just be, just, little specks of- white. Then once it got over me, they're full sized clouds. You could see 'em *form*ing. They're, like, growing bigger and bigger by the second, and my question is- How do they grow so *fast*? (pause)

Mrs. Miller: What is "it" again? Just clarify. What's growing? What's growing?

Martin: The, like, *cloud*. There was a little one- Just a speck of white. Off in the distance over to the light. Then by the time it got over to, like, a*bove* me, it was- a *huge* cloud.

Ronald: Because, when you see it farther away, um, if it's-

Martin: *No*! You could see it growing... You could actually see it-[hands moving outward] growing.

Ronald: Maybe it's doing really- *fast*. Like doing the cycle, as I said, really *fast*? And then that brings up more questions. Why it *grows*? So, I really don't know, except that it just does it really fast.

John: It could collect from other clouds.

Mrs. Miller: Well. What is John saying?...

[discussion ensues where the issue of the proximity of the mountains is raised]

Mrs. Miller: We were talking about *clouds*. When they get to a mountain. And I think Charlie (points) started this conversation. That the- (gestures) *clouds* when they get to a mountain. Do something. Right? Charlie? You want to further explain? Or-

Charlie: The clouds don't *stop* at the mountain. They *hit* the mountain. And stop there. Then, the clouds build up. And it *rains* on the side of the mountain. Which makes like, a little creek, or a river. Which goes down to water the land...

Mrs. Miller: But how does it explain- What side of the mountain are you talking about? Kind of give me a reference. The side that the *ocean's* on? Or- the side that Martin (points to Martin) is on?

Charlie: Rain forest is on [inaud] water and it builds up. But, what Laura was saying when she held her hand over the pot, was the steam wasn't going *through* her hand. It was kind of curving AROUND her hand and then rising back up.

MM: That's what Mark saw as well. Correct? [Mark nods.] So, what I'm still stuck on. .. I got this brainstorm. (claps hand) I think I need to see what you guys are talking about. So, I'm gonna put you in groups of four. So, put your hands down for a second. Because you guys *all* wanna say something. So, here's the question… Kinda switching to clouds. Right? You've got them coming up to the mountains. Something happens. But then there's clouds on the other side (pointing to Martin) where Martin is in the desert, right? So. I think the question I want you to answer for me, is- What's happening from one side of the mountain to the other? What's going on with the clouds? And I'm going to give you some boards and markers, but I want you to talk about it first. What's *happening* with the clouds from one side of the mountain- How do they end up getting to the other side of the mountain?

Following this segment, the students break up into groups of four to discuss Martin's cloud phenomenon further. After ten minutes of small group work, the class reconvenes to allow each group to share its ideas and permit additional discussion. These conversations continue until the end of the hour-long session.

The two segments displayed above provide brief glimpses into Mrs. Miller's implementations of the inquiry-based water cycle module. A quick comparison of the two segments suggests that her instructional practice differed substantively from one to the other; how to effectively capture and characterize that difference, however, is not necessarily clear or straightforward. Thus, an important early step in studying teacher change in this setting is the identification of an appropriate lens by which to examine Mrs. Miller's practice. In the next section, I briefly delineate how others have attempted to characterize teacher change, identify a dimension of teacher practice that is aligned with teaching inquiry, and introduce the over-arching research questions that guided the design of this study.

1.4 Motivation for the current study

Describing teacher change

Few studies have actually described how teachers change with respect to their reform-based practice *inside* the classroom. Instead, researchers who have investigated teacher change have often based their claims on the results from teachers' performances on assessments and/or self-report surveys (e.g. Dresner, 2002; McGregor & Gunter, 2006; Radford, 1998), or studied teacher change in settings outside of the teachers' own classrooms (e.g. Sherin & Han, 2004; van Es & Sherin, 2006). Of the studies that have included *in situ* teacher observations as part of the research design, most employed standardized rubrics as a means to score aspects of a teacher's lesson along "criteria-based" continua (Blanchard, Southerland, & Granger, 2009; Hill, Blunk, Charalambous, Lewis, Phelps, Sleep, et al., 2008; Johnson & Fargo, 2010; Leonard, Barnes-Johnson, Dantley, & Kimber, 2010; Leonard, Boakes, & Moore, 2009; Luft, 2001). Such rubrics tend to result in overall composite scores that reflect a teacher's instructional approach along several dimensions as reflected by the lesson implemented (e.g. Bodzin & Beerer, 2003; Luft, 1999). These types of observational tools may represent appropriate means to describe and/or compare teachers' general instructional strategies; however, they may be less able to characterize specific moves or techniques used by a single teacher to promote and/or encourage student inquiry during one or more lessons. Thus, standardized rubrics may not be suitable if a researcher's aim is to describe the *process* of change (i.e. How did change occur? What did the change look like?), rather than simply document the *presence* of change (i.e. Did change occur?).

Recently, researchers in mathematics and science education have begun conducting finer-grained analyses of teachers' reform-based practice *in situ*. Sherin and van Es (2009), for example, dissected teachers' mathematics lessons into two-minute segments and characterized two areas of the teachers' practice as evident during each segment: (1) whether the teachers attended to students' mathematical ideas, and if so, (2) the extent to which the teachers reasoned about those mathematical ideas. The researchers then used the segment descriptions to characterize teachers' practice at different points during the academic year and draw conclusions about how teachers evolved with respect to these two dimensions. Blanchard, Southerland, and Granger (2009) adopted a different approach, coding *instances* of teacher and student questions according to Bloom's taxonomy, rather than assigning codes to instructional segments. Frequencies of different levels of questions were then compared pre-post intervention and used as partial evidence for teacher change. These types of detailed analyses of teacher practice afforded researchers a means to describe how teachers changed over time. A similar method of fine-grained analysis seems warranted when characterizing changes in Mrs. Miller's inquiry based instruction.

Teacher responsiveness

With respect to identifying a *dimension* of Mrs. Miller's practice on which to focus analyses, research in reform-based mathematics and science education has characterized an aspect of teacher's instructional practice that seems critical in helping students to develop their reasoning skills: that of a teacher's ability to attend ("notice") and respond to the substance[5] of students' ideas (Empson & Jacobs, 2008; Jacobs, Lamb, & Philipp, 2010; Levin, 2008; Levin, Hammer, & Coffey, 2009; Pierson, 2008; Sherin & Han, 2004; Sherin, Russ, Sherin, & Colestock, 2008; Sherin & van Es, 2005, 2009; Star & Strickland, 2008; van Es & Sherin, 2002, 2006, 2008). While I discuss several of these studies in greater detail in Section 2.3, I briefly draw upon this literature now in order to justify why I believe this dimension of a teacher's practice represents an appropriate locus of study.

It has been suggested that when teachers listen to their students' ideas and use these as the basis for further instruction, students are more likely to genuinely engage with the material under investigation and advance in their learning (Black and Wiliam, 1998; NRC, 2001). In the field of mathematics education, research has shown that when teachers attempt to discern students' mathematical explanations and solution strategies, many are able to construct instruction that is likely to encourage students to elaborate their mathematical thinking (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996; Franke & Kazemi, 2001; Pierson, 2008). In her dissertation work, Pierson (2008) found that teachers who are highly responsive to their students' mathematical ideas (those that actively take up and allow student ideas to form the basis of further discussion) are most likely to have students who exhibit significant learning gains. In the domain of scientific inquiry, researchers have suggested that a teacher's focused attention and response can better encourage students to refine and develop their questions, investigations, and explanations surrounding specific natural phenomena (Harlow, 2009; Levin, 2008; NRC, 1996; 2000, 2007). In light of these findings and suggestions, it seems reasonable to consider how a teacher attends and responds to the substance of her students' ideas as the means by which to view change(s) in her instructional practice.

Although there have been several studies over the past ten years that have examined teachers' ability to attend to, or notice, student thinking, many of them have centered on how teachers engage in this practice *outside* of the classroom setting. For example, Sherin and van Es conducted a series of studies on teachers' noticing in the context of professional development "video clubs" (e.g. Sherin & van Es, 2009; van Es &

Han, 2004; van Es & Sherin, 2006, 2008). While these researchers have amassed significant evidence to suggest that teachers *do* change with respect to what they notice in classroom instructional video segments, they have only recently begun to explore whether corresponding changes in practice occur in the classroom (Sherin & van Es, 2009). Additionally, Jacobs, Philipp, and their colleagues (2010) demonstrated that increased amounts of professional development improved elementary school mathematics teachers' abilities to notice students' mathematical thinking. Again, this work was conducted in a professional development setting rather than the classroom, however.

It is arguably difficult to definitively determine to what a teacher *attends* during instruction, although some researchers are currently developing some technologically innovative methods of illuminating this dimension of a teacher's practice (see Sherin, Russ, Sherin, & Colestock, 2008). The handful of studies that have examined how teachers attend and/or respond to student thinking *in* the classroom has instead tended to rely on analyzing *teacher talk* as a means to explore this aspect of their instructional practice. Specifically, content analysis of teachers' discourse has been predominantly used as a means to identify the locus of the teachers' attention and/or characterize the level of their responsiveness to their students' thinking. Levin, Hammer, and Coffey (2009), for example, used secondary science teachers' follow up statements and questions as evidence for the extent to which they took up and responded to their students' scientific ideas. Sherin and van Es (2009) examined teacher talk during two-minute instructional segments to determine the locus of the teacher's "selective attention" and "knowledge-based reasoning" during those intervals. Pierson (2008) analyzed teachers' utterances to code the level of teacher responsiveness (Low, Medium, High I, and High

II) as reflected by teacher talk during exchanges with mathematics students. Collectively, these studies seemed to indicate that a fine-grained examination of Mrs. Miller's talk could be productive in terms of characterizing Mrs. Miller's responsiveness to her students' thinking and afford a means to effectively describe her change in practice.

Re-examining Mrs. Miller's talk in Transcripts 1.3a and 1.3b with a lens on how she is responding to her students, it is clear that Mrs. Miller actively elicits student ideas and uses them as foundations for further discussion in both segments. Indeed, Mrs. Miller invites her students to contribute ideas about the phenomena under discussion and responds to her students by asking follow up questions in both excerpts. The manner in which Mrs. Miller *makes use* of those ideas, however, seems to differ between Transcripts 1.3a and 1.3b.

Consider Mrs. Miller's follow up questions in the first excerpt (Transcript 1.3a). Each question is arguably informed by her students' comments, for her questions either incorporate specific words and/or phrases used by the students or invite the students to exemplify or extend their previous comment. For example, Mrs. Miller asks Tommy, "Are they high or low?...What's the altitude of the clouds?" in lines 11-12, and she asks Jack, "Can you give an example?" in line 18. However, Mrs. Miller appears to use her students' comments as stepping-stones to particular concepts that she'd like them to understand, rather than as objects of further inquiry in their own right. When Tommy states that clouds drift higher as they move from ocean to land (Transcript 1.3a, lines 13-14), Mrs. Miller takes up and uses Tommy's word "higher" as a launching point for her next question, rather than pursing his idea that clouds move to higher elevations when they move from sea to land: "So they're gonna get *higher*. Is there someway we can connect how high they are with what they *look* like? (lines 15-16)." The phrasing of this and subsequent follow up questions (lines 19-20 and 24) make it clear that she'd like the students to recognize a connection between clouds' altitude and their appearance. In this excerpt, Mrs. Miller tends to ground her subsequent comments in her students' words, rather than the meaning behind those words.

This type of responsiveness seems to be in contrast with that exemplified in Transcript 1.3b. Once again, there is evidence to suggest that Mrs. Miller's follow up questions are grounded in her students' comments. This time, however, Mrs. Miller's questions seem to take up and respond to the *essence* of the students' ideas, without necessarily imposing a specific content agenda upon future discussion. For example, when Mrs. Miller invites several students to clarify and/or elaborate their statements (e.g. She asks Martin, "What's growing?" in lines 6, and she asks Charlie if he'd like to "explain [his previous comment] further" in line 18), her questions seem to be genuine attempts to understand their comments. She even invites her entire class to break up into small groups to further take up and elaborate a student's query. This move seems to be consistent with her own recognition that her students were engrossed in attempting to explain the phenomenon that Martin had witnessed in the desert: "I got this brainstorm…You guys *all* wanna say something…I think the question I want you to answer for me is, 'What's *happening* with the clouds from one side of the mountain- How do they end up getting to the other side of the mountain?'" (lines 27-35). Thus, Mrs. Miller spontaneously moved to have her students collectively pursue a student's idea, one that emerged via discussion, for a lengthy portion of a class session.

A comparison of the two class segments with a lens on responsiveness shows that Mrs. Miller seemed to take up and respond to her students' ideas to a much greater extent in Transcript 1.3b, perhaps indicating that Mrs. Miller transitioned to higher level of responsiveness from the first implementation to the second. These two segments represent only a small fraction of the amount of time Mrs. Miller and her class spent in the water cycle module, however. Over the course of three implementations, Mrs. Miller and her students ultimately spent in excess of forty-three hours engaging in discussions and activities associated with the water cycle module. Would such a focus on responsiveness ultimately prove a fruitful means by which to analyze Mrs. Miller's practice and make claims about her change?

Research Questions

Bearing in mind the interesting observations of Mrs. Miller's instructional practice as reflected in Transcripts 1.3a and 1.3b, and in full consideration of the current focus on inquiry teaching in science education, I generated the following overarching questions, both of which served to inform and constrain my dissertation research:

Within the context of endeavoring to teach science as inquiry in the classroom:

(1) How can a teacher's responsiveness to student thinking be characterized?

(2) How does one teacher, Mrs. Miller, change with respect to her responsiveness to student thinking over the course of three iterations of an inquiry-based module?

In order to answer these questions, I analyzed data from four sources: Mrs. Miller's classroom sessions from her three implementations of the water cycle module, debriefing interviews with Mrs. Miller directly following her instructional sessions, additional interviews with Mrs. Miller, and professional development sessions of which Mrs. Miller was a part. These sources of data, as well as the associated methods of data collection, are described in greater detail in Chapter 3.

1.5 Significance of the study and contributions to the field

I conclude this chapter with a brief overview of how this work contributes to the educational research community, both at methodological and practical levels. In the first subsection, I describe how this research can serve to move the field forward methodologically. I then present the practical implications of the study.

Methodological contributions

Schoenfeld (1998) described a shift in educational research from examining teaching and learning in the laboratory setting to the more authentic, “true” educational setting of the classroom. He argued that research in such “non-sterile” environments was more difficult, because there were myriad factors that could play a role in determining an individual’s behavior. In order to advance in our understanding of the theoretical underpinnings of behavior, he contended, it was necessary to examine such behavior at a fine-grained level in such complex settings.

As previously discussed, there have been only a few studies that have investigated the nature of a teacher’s change in practice *in situ*. Studies of teacher change have often focused either on self-reports and/or assessments (e.g.Dresner, 2002; McGregor & Gunter, 2006) or investigated teacher change in settings outside of the classroom (e.g.

Sherin & Han, 2004; van Es & Sherin, 2006, 2008). Thus, there are few methods currently available by which to research teachers' practice in the classroom. This study presents a new methodological construct that can be used to characterize teachers' instructional practice via quantitative and qualitative analyses of a teacher's discourse. Furthermore, this study uses that same construct to trace a single teacher's change in practice as she endeavored to teach science as inquiry *in the classroom*. This type of research is consistent with Schoenfeld's (1998) "call to action," for it describes a means by which researchers can conduct fine-grained analyses to characterize teacher practice in the "non-sterile" environment of the classroom.

Practical significance

In the context of educational reform, there continues to be a call for a deeper understanding of how established teachers change their practice within specific content areas (Simon & Tzur, 1999; Schwartz, 2009; Thompson et al., 2009). It has been suggested that such an understanding can lead to more informed teacher training, in terms of developing pre-service and professional development curricula in these areas (Schoenfeld, 1998; Schwarz, 2009; Simon & Tzur, 1999; Thompson et al., 2009). The current emphasis on scientific inquiry in the state and national standards presents the field with a critical need to understand how teachers develop competency in their ability to teach science as inquiry (Harlow, 2009; Schwartz, 2009; Thompson et al., 2009). This study helps to fill these gaps by providing a rich portrayal of how an experienced teacher evolved in teaching science as inquiry.

The fact that this case study focuses on a capable teacher with over twenty-five years of instructional experience is also of particular interest. It has been previously suggested that experienced teachers are less amenable to adopting new curricula and/or pedagogy, especially if the innovation(s) requires a radical alteration in their practice (Guskey, 1985; Luft, 2001). The results from this study show that even teachers with over twenty-five years of classroom experience are capable of implementing change. A focus on such a teacher in transition may help educational specialists design more thoughtful and tailored in-service teacher education programs to help other experienced teachers advance in their ability to promote scientific inquiry in their classrooms.

Finally, this work documents how a teacher changed her inquiry instructional practice in the context of a flexible and “responsive” inquiry-based curricular module. Although it is beyond the scope of the proposed study to investigate the direct impact the curriculum may have had on her change, the responsive curricular module was very likely an important factor in Mrs. Miller’s change in practice. Such a minimally guided curriculum, without prescribed learning outcomes and lesson plans, provided an excellent arena for Mrs. Miller to attend and respond to her students’ ideas. Indeed, it may be that such a curriculum encourages teachers to engage in these inquiry practices *more quickly* than more traditional or guided-inquiry curricula, since teachers need to attend to their students’ thinking in order to determine which avenue to pursue next. An extended implication of this research may be to show that a responsive curriculum, as conceived by the Learning Progressions for Scientific Inquiry project, *can* provide the space for a teacher to change in how she responds to her students’ thinking and, thus, comprises a foundation from which additional work in this area can build.

I now present a synthesis of the relevant literature that situates the proposed study and informs the research questions, design, and methodology.

CHAPTER 2: REVIEW OF THE LITERATURE

This case study describes an in-depth analysis of a teacher's practice as she implemented reform-based instruction. This study is informed by three overlapping strands of educational research literature: (a) inquiry in science education, (b) teacher change, and (c) attending (or noticing) and responding to students' thinking. These areas are reviewed in the sections below. In each section, I make specific reference to how the proposed study is situated within and can build upon the research presented in these bodies of literature.

2.1 Inquiry in science education

As stated in chapter 1, teaching science as inquiry is currently viewed as a critical component of science education and is included in national and state science standards at both the primary and secondary school levels (California Department of Education, 2000; NRC, 1996, 2000, 2007). To date, there has been little research characterizing how a teacher's practice changes as he or she enacts inquiry-based science instruction. A longitudinal case study of a veteran teacher in transition would provide the educational community with data regarding the development of science inquiry practice. Such data could inform future endeavors to support experienced teachers to teach inquiry effectively (Schwartz, 2009; Thompson et al., 2009).

My review of inquiry in science education consists of three sections. First, I provide an historical overview of the efforts to teach science as inquiry. Second, I describe how inquiry is currently conceptualized and enacted in science education. I conclude with a brief discussion of how members of the Learning Progressions for Scientific Inquiry (LP) project conceive of scientific inquiry and how this perspective informed this case study.

Historical background: Science as inquiry

The current impetus for inquiry in science education is not the first of its kind. Over the past century, vocal advocates have introduced the idea of "inquiry" as a key component of teaching and learning science more than once in the spirit of reform. At each point in time, some educators embraced the notion of teaching science as inquiry, while others continued to teach science as a set of facts to be memorized. The confusion and ambiguity surrounding inquiry today seem to echo those of previous times.

Prior to 1900, science was considered by most educators to be an accumulated body of knowledge that students were to learn through direct instruction. Many science instructors relied on the recitation of facts as the means by which students accrued this knowledge (Lawson, 2010; NRC, 2000). Such teaching methods began to lose favor in the early twentieth century, however, with many educators questioning what science was and how it should be taught (Bybee, 2000). Laboratory experiences came to be valued by some educators as a means of exposing students to the physical world and providing them with a nice complement to lecture and recitation classes (Bybee, 2000; DeBoer, 1991). Approaches to laboratory instruction were varied and ranged from discovery-type investigations, where the students were to unveil scientific principles on their own, to verification-type laboratory exercises, where the students were to confirm scientific principles already learned through lecture (DeBoer, 1991). Some educators instead took an intermediate stance on lab work, however, encouraging students to seek answers to questions for which they (the students) did not yet know the answers. According to Edwin Hall and his colleagues at Harvard University, this latter approach to "inquiry" afforded students the opportunity to assume the role of investigators exploring and reasoning about natural phenomena (Smith & Hall, 1902, as cited by DeBoer, 1991).

John Dewey, the noted educator and philosopher of education, advocated for instructional practice emphasizing science as a *method* of inquiry. He argued that science was much more than an accumulation of knowledge; science entailed a specific way of knowing, an "attitude" of mind (NRC, 2000). "Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter" (Dewey, 1910/1964, p. 187). Dewey considered it to be important that students themselves should participate in the making of knowledge, in order to best understand it as a method of knowing. Despite Dewey's suggestions, confusion and disagreement lingered within the educational community as to how science should it be taught. As a result, the focus of mainstream science instruction continued to be teaching science as a body of accumulated facts, rather than as a process by which knowledge was created and refined (DeBoer, 1991).

With the success of Sputnik, a national push emerged within the United States to reform math and science education in the late 1950s and early 1960s. To this end, the American government funded a series of projects to develop instructional materials aimed at revolutionizing science education in the different scientific disciplines (i.e. biology, chemistry, physics). One of these projects, the *Biological Sciences Curriculum*

Study (BSCS), was particularly successful in developing and promoting reformed-based curricular materials that included a large science-as-inquiry component (DeBoer, 1991). Funded by the National Science Foundation, the BSCS was a massive effort to reorganize the teaching of introductory biology through the coordination of research in learning and instruction. The outcomes of this project included the generation of the 5E Instructional Model[6] and a series of educational resources (Lawson, 2010), all of which were designed to reflect "the [true] nature of the scientific knowledge and process" (p. DeBoer, 1991, p. 151)[7].

One member of the BSCS project team, Joseph Schwab, became particularly vocal about the need for infusing science education with inquiry (or "enquiry," as he spelled it). At the time, science as a discipline was no longer considered a fixed body of knowledge, but one that was susceptible to revision, extension, and growth as new evidence emerged (Bybee, 2000). Schwab believed that science instruction needed to reflect a similar change (DeBoer, 1991; NRC, 2000). Instead of teaching science as a "nearly unmitigated *rhetoric of conclusions* in which the current and contemporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths" (Schwab, 1962, p. 24), Schwab contended that science education needed to reflect the tentativeness and flexibility of scientific knowledge. Additionally, science instruction needed to expose students to the evidence by which scientific claims were supported (DeBoer, 1991). Schwab called for more laboratory experiences for students and endorsed laboratory work as a precursor to classroom study (Bybee, 2000; NRC, 2000). He felt that inquiry learning should parallel that which occurred in the practice of science: evidence would lead to explanation and, ultimately, the refinement of that explanation

(NRC, 2000). Furthermore, Schwab claimed that *discussion* was an important vehicle for inquiry since it was through discussion that "students learned that many questions have no 'right' answers, but rather answers that are *more or less* defensible in light of the evidence" (DeBoer, 1991, p. 165).

Although the BSCS (and Schwab's) efforts to re-organize science education were extensive and embraced by many in the educational community, the outcome was not as effective as was originally anticipated (NRC, 2000). Teaching science as *process* remained largely secondary to teaching science as *content*. In a 1986 article in the *American Biology Teacher*, Constenson and Lawson published the findings of a survey administered to a sample of practicing biology teachers. They found that teachers were generally hesitant to incorporate inquiry into their teaching, citing a variety of reasons for such reluctance. These reasons included that inquiry took too much time, was too expensive, involved experiments that put students at risk, and limited a teacher's ability to assess students' progress. The results of the survey showed that despite inquiry's emphasis by curriculum developers and researchers, many teachers of science continued to resist teaching science as inquiry (Bybee, 2000).

In 1985, the American Academy for the Advancement of Science [AAAS] christened a long-term initiative aimed at the national reformation of science education at the primary and secondary school levels. Among the numerous publications that emerged from this endeavor were *Science for All Americans* (1989) and the *Benchmarks for Science Literacy* (1993), both of which strongly endorsed the incorporation of inquiry into the teaching of science. This newly invigorated climate of national reform in science education prompted the National Research Council (NRC) to coordinate an effort to generate a set of national science standards in 1991. The result of this effort was the publishing of the first National Education Science Standards (NSES) in 1996, which included a large component devoted to familiarizing students with scientific inquiry at all grade levels (NRC, 1996).

As a result of the work of John Dewey, Joseph Schwab, and others, the pursuit of inquiry remained a recurrent strand in science education, albeit one often relegated to the background, for close to a hundred years. The impetus to generate the *Benchmarks for Science Literacy* and *NSES* helped to bring inquiry back to the forefront. I turn now to the characterization of scientific inquiry by the NSES and how the educational community has responded to the latest impetus to teach science as inquiry.

Current approaches to scientific inquiry: The NSES and beyond

As stated above, the current National Science Education Standards (NSES) place a large emphasis on inquiry in science education. Indeed, both the national content standards and national teaching standards include strands that specifically refer to scientific inquiry. Content Standard (A) specifically mandates that students should develop two different competencies with respect to scientific inquiry: "Abilities necessary to *do* scientific inquiry and understanding *about* scientific inquiry" (NRC, 1996, p. 105, emphasis mine). In order to help students meet these standards, Teaching Standard (A) obliges teachers to necessarily "plan an inquiry based science program" (NRC, 1996, p. 30). It stands to reason that teachers should therefore expend time and effort to design activities that encourage students at each grade level band (K-4, 5-8, 9-12) to *engage in* and *learn about* the process of scientific inquiry.

In order to clarify what is meant by "scientific inquiry," the NSES go to great length to define the term and elaborate the types of activities that are representative of the endeavor:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world…[These activities include] posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23-24)

Such characterization seems to make several ideas plain. First, inquiry refers to both the scientific endeavor of scientists *and* the scientific endeavor of students. Second, student activities should familiarize students with the process by which scientists understand the natural world. Third, there are numerous facets to engaging in the process of scientific inquiry. Last, there is a range of activities (including the examination of books and planning of investigations) in which students can engage that are consistent with various aspects of scientific inquiry.

The image of inquiry that is portrayed in the NSES is broad enough to encompass numerous instructional activities, as long as the students come away with experiences consistent with aspects of scientists' practice. But what *is* it that scientists do? How can teachers encourage students to *do* it? Given the limited background that many instructors have in science (Dresner, 2002; Tilgner, 1990; Wallace & Louden, 1992) and the simplistic portrayal of inquiry provided in many textbooks (Chinn & Malhotra, 2002;

McComas, 1996; Reiff, Harwood, & Phillipson, 2002), many science educators remain unclear as to how to implement inquiry in the classroom. Some teachers interpret inquiry as simply more content to learn (Wee et a., 2007). Others equate inquiry with the steps of the prescriptive “scientific method” (Finley & Pocovi, 2000; Tang et al, 2008; Windschitl & Buttemer, 2000). Still others consider any “hands-on” activity as means to provide students with inquiry learning experience (Lardy, 2011; Sarkar & Frazier, 2008). Unfortunately, treatments such as these may fail to encourage students to develop an understanding of and appreciation for the scientific enterprise (Sarkar & Frazier, 2008; Tang et al., 2008). In fact, research has shown that these activities may result in understandings that are actually *antithetical* to the true nature of scientific inquiry.

In a 2008 New Zealand study, Hume and Coll investigated student learning as a result of classroom-type inquiry activities. Similar to the NSES in the United States, New Zealand’s national curriculum in science encourages the use of authentic inquiry (i.e. that which is consistent with inquiry practiced by scientists) in the classroom. However, Hume and Coll found that teachers tended to implement activities that were highly structured and “closed,” in order to fit the activities into allotted time frames and meet expectations set by high-stakes assessments. The researchers claimed that although students were indeed learning as a result of these “inquiry” activities, the substance of that learning was limited, primarily procedural, and concerned following a set of steps to answer a given question. It seemed that the students’ participation in the structured tasks did little to stimulate their creativity or critical thinking and generally fostered a simplistic, linear, and narrow view of scientific inquiry.

Chinn and Malhotra (2002) investigated how typical school inquiry tasks compared to the authentic inquiry as practiced by scientists. Specifically, they compared the cognitive processes and epistemologies associated with inquiry as practiced by scientists and those associated with students completing the "simple inquiry tasks" as described in middle school and elementary textbooks. The researchers found that the simple inquiry tasks often required students to reason in dramatically different ways than scientists did. For example, while scientists generated their own questions; students often did not. Scientists tended to design complex procedures in order to answer their questions; students instead tended to follow prescribed linear procedures to answer the questions provided to them. The researchers claimed these school tasks actually perpetuated epistemologies altogether different from those underlying authentic science. They contended that school-based tasks portray inquiry as a process that uses simple, linear reasoning to understand known phenomena, rather than one that involves complex, iterative, reflective reasoning to understand unknown phenomena.

The findings of Chinn and Malhotra (2002) and Hume and Coll (2008) suggest that many school science tasks limit students' experience of scientific inquiry and may actually prompt beliefs and understandings that stand in direct opposition to those maintained by scientists. While the NSES maintain that scientific inquiry in school should mirror aspects of the practices in which scientists themselves engage, it appears as if many teachers' enactment of inquiry does not capture the essence of these practices or generate the type of understandings consistent with authentic inquiry. Additional support is required if teachers are to teach inquiry more effectively.

To this end, science education researchers are engaging in various areas of research in order to develop means of supporting teachers as they endeavor to teach science as inquiry. One strand of this research involves the attempt to make the practices and methods in which scientists engage more explicit. Over the past two decades, several studies have begun to unpack the practices of scientists and make them more accessible to those outside the discipline. Some of this work has focused on explicating components of activities in which scientists often engage, such as how scientists create, interpret, and communicate about representations of natural phenomena (Kozma, Chin, Russell, & Marx, 2000; Roth & Bowen, 2001). Other research efforts have sought to characterize specific aspects of the myriad pathways scientists may follow during investigations (Harwood, Reiff, & Phillipson, 2002; Park et al., 2009). The results of this body of work can be used by various members of the educational community (e.g. teachers, teacher educators, curriculum developers) to generate educational activities and curricula that are more consistent with the scientific enterprise.

Another area of educational research has centered on designing, implementing, and studying the effects of various pedagogical interventions aimed at promoting inquiry in the classroom. Many of the programs include substantive professional development sessions and workshops that provide teachers with opportunities to engage in their own inquiry-based learning. Some of these programs focus on promoting specific aspects of inquiry, such as helping teachers support their students' construction of explanatory models (Harlow, 2009; Windschitl et al., 2008) and/or developing arguments explaining phenomena (Berland & Reiser, 2009; McNeill, 2009; Sandoval, 2003; Sandoval & Reiser, 2004). Others have teachers conduct their own investigations as a means for the teachers to learn what inquiry is (Dresner, 2002; Jeanpierre, Oberhauser, & Freeman, 2005). Programs such as these are designed on the premise that if teachers *experience* inquiry, they will be more likely to *teach* inquiry.

While curricular and programmatic interventions may differ in perspective, focus, and structure, they are generally aimed at encouraging teachers and students to engage in more authentic inquiry in the classroom. This overarching goal is consistent with that of the Learning Progressions for Scientific Inquiry (LP) project, from which the case study of Mrs. Miller emerged. I now describe the LP project's approach to inquiry and how it informed this research study.

The Learning Progressions' perspective on inquiry

The Learning Progressions (LP) project is similar to other inquiry-based interventions in that it emphasizes teaching science as inquiry and includes a large professional development program to support teachers as they learn to enact inquiry in the classroom. The project's primary objectives are to help elementary and middle school teachers improve their ability to promote scientific inquiry in their classrooms and to better understand how students change in their ability to engage in scientific inquiry over time. What distinguishes this program from others, however, is: (a) how the project's staff conceptualizes inquiry, (b) the design of the professional development, and (c) the structure of the curricular materials. The following paragraphs briefly outline these unique aspects of the LP project.

The LP team members adopt a perspective on inquiry that is consistent with that presented in Hammer et al. (2008): "Inquiry in science is the pursuit of coherent, mechanistic accounts of natural phenomena" (p. 150), where "mechanistic" refers to the notion that events result from chains of cause and effect. When individuals (i.e. teachers and/or students) engage in considering, making sense of, and accounting for everyday events, they are necessarily *doing* inquiry. Hence, the focus of much of the LP project's work is to encourage students and teachers to engage in meaningful discussions generating, elaborating, and evaluating explanations for familiar natural phenomena.

In order to support teachers in their endeavor to teach science as inquiry, the LP project includes extensive, long-term professional development where teachers act as learners. The program includes opportunities for teachers to engage in a number of scientific inquiry experiences where they consider, debate, and investigate explanations for natural phenomena. For example, during the summer of 2010, several of the teachers spent a week considering the question, "Why doesn't it rain more in San Diego?" Discussions that resulted from this initial question touched upon such topics as the connection between temperature and pressure, the nature of the different states of matter, and global weather patterns. Additional LP activities include having the participant teachers watch recorded video from their classrooms and discuss student ideas as they emerge during classroom activity. Such activities are aimed at encouraging teachers to recognize the potential merit[8] of students' ideas and help them create lists of potential instructional "next moves" grounded in those ideas.

In addition to designing these biweekly professional development activities for participating teachers, the LP project is responsible for generating a series of inquiry-based curricular modules for teachers to implement in their classrooms. These curricular modules provide teachers with generative opening questions (similar in structure to the one regarding rain in San Diego), as well as suggest potential avenues for the teachers to pursue during subsequent discussion sessions. Rather than imposing structure or sequence, however, these follow-up pathways simply represent possibilities as to where the teachers *could* go. Ultimately, the teachers are responsible for deciding what happens next, ideally basing that decision on emergent student ideas (see Sections 1.2 and 3.3 for additional descriptions of the LP modules).

A unique feature of the LP program is its focus on responsiveness. Both the PD activities for the teachers and the curricular modules for the students involve largely open-ended discussion components for the respective learners. These "inquiry activities" do not have a structured plan nor are they associated with specific learning outcomes that the learners are expected to achieve. Rather, the inquiry activities are designed with built-in flexibility to allow emergent ideas to drive the direction of subsequent instructional sessions. In many cases (both in the PD sessions and in the classroom), there is not necessarily a specific answer that the learners are attempting to discover. Instead, the teacher and student participants engage one another in debating and defending ideas, evaluating the merits of ideas, testing ideas, and discussing the implications of ideas. The nature of this type of experience is consistent with inquiry as conceived by Dewey in the early twentieth century, Schwab in the 1960s, the current NSES, and the processes in which scientists engage. Thus, when learners engage in these types of discussions and activities, they are *doing* inquiry. It is in this type of professional development program that the focal teacher, Mrs. Miller, took part and which provided the context for the change in her inquiry instructional practices over the course of three academic years. This analysis of Mrs. Miller's instructional practice has resulted in a rich characterization of how an experienced teacher evolved in teaching science as inquiry. I now review the relevant literature on teacher change.

2.2 Teacher change in the context of math and science reform

Researchers have generated models of learning-to-teach that characterize the stages that teachers pass through as they acquire expertise in their field (Berliner, 1988, as cited in Kwo, 1994; Kagan, 1992). Such models often include a stage late in the trajectory that describes teachers' development of routines of classroom management and instruction. As teachers construct and master these types of routines and scripts, they become automatized (Schoenfeld, 1998), allowing teachers to turn more focused attention to their students' knowledge[9] (Kagan, 1992). Once teachers become established in their profession and achieve this level of expertise, however, some content that it may be more difficult for them to implement radically different curricula and/or pedagogy (Guskey, 1985; van Es & Sherin, 2008), particularly when the innovations are mandated by policy makers, staff developers, and/or school administrators (Richardson, 1998). This difficulty may be because such innovations disrupt teachers' established routines (Hammerness, Darling-Hammond, Bransford, Berliner, Cochroan-Smith, McDonald, et al., 2005), are less consistent with teachers' prior conceptions about teaching and learning (Johnson & Fargo, 2010; Jeanpierre et al., 2005, Richardson, 1998), and/or do not work as perceived by the teachers themselves (Guskey, 1985; Richardson, 1998). Even so, veteran teachers are capable of, and often achieve, change in their practice (Richardson, 1998).

The following section reviews studies that have explored teacher change in the context of mathematics and science education reform. First, I provide an overview of what I mean by "teacher change." I follow this with an examination of the studies that have investigated teacher change to date. In this review, I focus on describing the dimensions of teacher change that have been examined and the methods by which those dimensions have been studied. In the final paragraphs of the section, I explicate how the case study of Mrs. Miller study extends and elaborates previous work in the field.

Defining "change"

It is important to define what is meant by "teacher change." Teachers shift their instruction every day, as a result of the dynamic, fluid nature of their professional activity (Richardson, 1990). While arguably a critically important aspect of teachers' activity, this type of immediate change that results from on-the fly decision-making is not what is meant here. By "teacher change," I refer instead to sustained change in teachers' *practice*, consistent with that as characterized by Simon & Tzur (1999):

> Teachers' practice indicates not only everything teachers do that contributes to their teaching (planning, assessing, interacting with students) but also everything teachers think about, know, and believe about what they do. In addition, teachers' intuitions, skills, values, and feelings about what they do are part of their practice. (p. 253-254)

Educational researchers have alternately referred to this type of teacher change as teachers' "professional growth" (Kagan, 1992), "teacher growth" (Franke & Kazemi, 2001), "teacher learning" (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Sherin & van Han, 2004), and "teacher development" (Simon & Tzur, 1999). For the purposes of this study, I choose to adopt the phrase *teacher change* rather the alternatives for the following reasons. First, the word “change” does not necessarily imply a steady, developmental-type progression towards a correct practice, such as might be implied by the terms “development” or “growth.” Second, I do not mean to suggest changes in a teacher’s mental processes only, as might my adoption of the phrase “teacher learning.” My selection of *teacher change* simply connotes that a teacher is shifting, possibly episodically, in one or more dimensions of her practice, as she attempts to enact a novel form of instruction.

Studies of teacher change: A review

There appears to be a dearth of studies in mathematics and science education that investigate teacher change empirically. Of the research that does exist, the studies differ in terms of dimensions of change investigated, duration of project, number and types of subjects involved, and methods of data collection and analysis used. Table 2.1 presents an overview of the studies published on teacher change in the areas of math and science reform, with specific attention paid to the dimensions of change explored, the methods used to investigate change, and the research findings presented. In the following paragraphs, I highlight some of the notable features of this body of work.

Table 2.1 *Studies of Teacher Change in Mathematics and Science Education*

Study	Intervention	Teachers (Ts)	Change dimension(s)	Methods	Findings
Krajcik et al. (1994) Ladewski et al. (1994) Marx et al. (1994)	Project-based science instruction PD program	MS Ts	Beliefs Conceptions Instructional strategies	Integration across: interviews, emails, reflections	As a result of an iterative sequence of enactment, collaboration, and reflection, Ts changed in their practice
Fennema et al. (1996)	CGI (PD focused on children's mathematics thinking)	21 ES Ts	Beliefs Instructional strategies	Pre-during-post CGI beliefs instrument Class observations	Ts adopted more sophisticated beliefs and instructional strategies; Changes in instruction were directly related to student learning gains
Radford (1998)	LIFE (inquiry-based PD, focused on middle grades)	90 life science Ts (all grade levels)	Knowledge Skills Attitudes	Pre-post assessment Pre-post assessment Self-report survey	Ts improved in all three dimensions; Participating Ts' skills and attitudes much higher than Ts who did not participate
Luft (2001)	IBDC (in-service inquiry-based science program)	14 secondary Ts	Beliefs Instructional strategies	Pre-post interviews Class observations	Novices more likely to change beliefs; experienced Ts more likely to change pedagogy
Bell (2002)	ENVISION (EnvSci inquiry-based PD)	5 MS Ts	Knowledge of inquiry Instructional strategies	Pre-post surveys Pre-post assessment Class observations	Effects of different levels of PD varied as evident in T's knowledge and use of inquiry; Ts tended to incorporate more student centered elements in instruction

Note. Ts = teachers. [a] Students were also included in the program. [b] The instructional strategy of noticing was assessed *outside* the classroom, during PD sessions.

Table 2.1 (continued) *Studies of Teacher Change in Mathematics and Science Education*

Study	Intervention	Teachers (Ts)	Change dimension(s)	Methods	Findings
Dresner (2002)	Teachers in the Woods (Forest ecology field-experience program)	130 MS and HS Ts[a]	Content Skills Instructional strategies Attitudes	Pre-post survey Pre-post survey Self report surveys Self report surveys	Ts reported increased understanding of content and skills, as well as increased proficiency in teaching field science and inquiry
van Es & Han (2004) Sherin & van Es (2005)	Video Clubs	4 MS Ts	Instructional strategies (employed outside of class)[b]	Comments made in PD sessions and interviews	Ts increased their attention to and reasoning about students' mathematical thinking
Jeanpierre et al. (2005)	Ecology research institutes	5 groups of Ts[a]	Science content Skills knowledge Instructional strategies	Pre-post test Pre-post test Self-report surveys	Understandings of science content and skills improved; Ts implemented higher quality inquiry-based activities.
McGregor & Gunter (2006)	Inquiry-based science PD	Secondary Ts in 91 schools	Instructional strategies	Self-report surveys; Interviews	Ts reported using inquiry-based strategies more often: • Open-ended Qs • Student collaboration • Student predictions • Student explanations
Wee et al. (2007)	ENVISION (EnvSci inquiry-based PD)	4 Ts	Conceptions of inquiry Design of inquiry activities Instructional strategies	Pre-post concept maps Pre-post assessment Class observation and interviews	Understandings of inquiry improved as a result of intervention, but not as a result of enactment; Design of inquiry activities improved but practice did not actualize this

Note. Ts = teachers. [a] Students were also included in the program. [b] The instructional strategy of noticing was assessed *outside* the classroom, during PD sessions.

Table 2.1 (continued) *Studies of Teacher Change in Mathematics and Science Education*

Study	Intervention	Teachers (Ts)	Change dimension(s)	Methods	Findings
Blanchard et al. (2009)	MET (marine science inquiry-based PD program)	4 Ts	Understandings of inquiry	Pre-post survey	All Ts changed in their enactment of inquiry; Ts with more sophisticated understanding of teaching and learning more likely to change other areas of their practice (beliefs, goals, values)
			Instructional strategies	Class observations	
			Beliefs Goals Values	Integration across: observations, interviews, surveys	
Sherin & van Es (2009)	Video Clubs (in-service PD using video displaying math class activity)	7 ES Ts	Instructional strategies	Comments made during PD sessions[b] Class observations	Ts increased their attention to and reasoning about students' mathematical thinking
Johnson & Fargo (2010)	TBD (inquiry-based science PD program)	16 MS Ts	Instructional strategies	Class observations	Ts that participated in the intervention improved their instruction in comparison to Ts that didn't participate in the intervention

Note. Ts = teachers. [a] Students were also included in the program. [b] The instructional strategy of noticing was assessed *outside* the classroom, during PD sessions.

As mentioned above, teachers' practice encompasses many different dimensions, including their content knowledge, their attitudes and beliefs about teaching and learning in their discipline, and their instructional strategies and activities. The methods of data collection and analysis employed in specific studies on teacher change have varied, depending upon the dimension(s) of teacher practice examined for change. For example, several researchers have utilized pre-post instruments to investigate whether teachers' knowledge of science content and/or inquiry changed as a result of particular professional development programs (Bell, 2002; Blanchard et al., 2009; Dresner 2002; Jeanpierre et al., 2005; Radford, 1998; Wee et al., 2007). While the structure and format of such instruments vary among studies (e.g. concept maps vs. surveys vs. structured assessments), the assessments tend to be administered prior to the intervention as a "pre-test" and again following the intervention as "post-test." The findings of these studies generally suggest that the teachers' knowledge improves as measured by these instruments.

Researchers have tended to use self-report surveys when investigating changes in teachers' attitudes toward science teaching and learning. For example, Radford (1998) administered Likert-scale surveys to the teachers pre and post-intervention to explore changes in teachers' attitudes toward science, while Dresner (2002) analyzed teachers' reflective responses to open-ended questions when investigating their attitudes towards teaching and learning inquiry. In both cases, the researchers found that teachers had more positive attitudes towards science and their science classroom experience following their participation in professional development programs.

Researchers have been more methodologically varied with respect to how they have measured changes in teachers' beliefs. Luft (2001) utilized results from structured and semi-structured interviews to attribute beliefs about inquiry teaching and learning to her subjects, while Fennema and her CGI colleagues (1996) utilized responses to the CGI Belief Scale as means by which to attribute beliefs about mathematics teaching and learning to teachers at different points during the CGI program. Krajcik and his colleagues (Krajcik et al., 1994; Ladewski et a., 1994; Marx et al., 1994) and Blanchard et al. (2009) relied on integrating data from a number of sources, including those from personal reflections, interviews, and classroom observations, to make claims about changes in teachers' beliefs. Collectively, the results from these belief studies suggest that participation in professional development programs and/or the enactment of novel pedagogy promote change in some teachers, but not others. Researchers have contended that additional factors, such as the extent of teachers' experience, their previous educational training in theory based-practice, and/or their initial beliefs, play a role in whether or not teachers change in this dimension of their practice (Blanchard et al., 2009; Luft, 2001).

With the exception of Radford (1998), all of the reviewed studies on teacher change examined changes in at least one aspect of teachers' *instructional* practice. Broadly speaking, this area of teacher practice includes the pedagogical strategies, moves, and activities a teacher utilizes as he or she engages his or her students in classroom instruction. Researchers in mathematics and science education have explored change along several dimensions of instructional practice, including: teachers' incorporation of reform-based activities (e.g. problem-solving tasks or inquiry-centered investigations), teachers' use of cooperative learning with students, the degree to which a teacher acts as a guide during activities, and the focus of teachers' attention.

While some of the research studies have utilized multiple sources of data to substantiate claims of change in teachers' instructional practice (e.g. Krajcik et al., 1994), researchers generally have relied either on self-report surveys and/or classroom observations as the predominant source of data on which to base claims of change. Self-report surveys used in teacher change studies are often questionnaires containing several open-ended prompts, each of which ask teachers to describe specific aspects of their classroom teaching. Some researchers that utilize such surveys assign codes to teachers' responses based upon specific criteria. McGregor & Gunter (2006), for example, scored survey responses according to how frequently the teachers reported using specific techniques and strategies to teach inquiry (never, occasionally, often, always). Other researchers use more interpretive methods when evaluating self-reports for evidence of change. Dresner (2002) asked teachers to report on different elements of their inquiry-based instruction (e.g. having students formulate scientific questions or design scientific experiments) at different points during the professional development program. The author and his colleagues then examined the teachers' responses for changes in how they described their respective inquiry implementations. Jeanpierre, Oberhauser, and Freeman (2005) similarly used teachers' descriptions of their classroom inquiry activities to assign teachers to one of three levels of proficiency regarding their inquiry instruction: doing inquiry, almost doing inquiry, or not doing inquiry. The researchers then compared the teachers' descriptions before and after participation in an intervention to make claims about their change in instructional practice. All of these research studies found that teachers reported implementing higher levels of inquiry-based instruction following their participation in their respective professional development programs.

Classroom observations were employed in approximately half of the research studies investigating change in teachers' instructional practice. Table 2.2 summarizes features of the various assessment methods used in the six observational studies. In general, these studies utilized structured observational protocols as means to assess one or more dimensions of teachers' instructional practice as manifested *in the classroom* at various points in time. These observational protocols tended to incorporate the use of one or more assessment tools strategically designed to ascertain the effectiveness of a particular professional development program. The observational instruments typically required observers to either assign numeric scores to elements of a teachers' practice or locate aspects of a teachers' practice along an assessment continuum. Once validated as part of one particular project, these assessment tools could be adapted for further use in other educational research studies (e.g. Bell's adaptation of the EIOR to generate the IAT, 2002).

In her 2001 study, Luft utilized the Extended Inquiry Observation Rubric (EIOR) as a means to describe observable changes in teachers' inquiry practice as a result of their participation in an eighteen-month extended inquiry professional development program. The EIOR is an observational tool that requires observers to assign a score of 1 - 5 to different categories of a teacher's science lesson. The eight categories of the EIOR reflect "sound science instruction" and align with the inquiry elements presented in the National Science Education Standards (Luft, 1999). The categories include such instructional strategies as incorporating cooperative learning, having students engage with inquiry-type questions and encouraging students to design and conduct investigations. Bell (2002) similarly used the numeric Inquiry Assessment Tool (IAT) to evaluate teachers' instruction before, during, and after their participation in the ENVISION professional development program. The IAT, a rubric adapted from the EIOR, afforded Bell and her colleagues a means to assign numeric scores to eleven "inquiry" aspects of the teachers' science lesson. Johnson & Fargo (2010) utilized the Local Systemic Change (LSC) protocol to evaluate several aspects of the teachers' instructional practice once a month over the course of two academic years. The LSC is considerably lengthier than the previous two instruments, requiring observers to score a teacher's lesson along thirty-three different dimensions. These dimensions are classified within four general categories: (1) lesson design, (2) lesson implementation, (3) classroom culture, and (4) math and science content. Once the individual dimensions are scored, the observer synthesizes across the marks to generate a "synthesis rating" for each of the four categories (Haney, Lumpe, Czerniak, & Egan, 2002). In all three studies, researchers used changes in one or more of the teachers' scores as evidence for change in the respective dimension(s) of the teachers' instructional practice.

Table 2.2 *Comparison of Observational Methods Across studies that Employed Classroom Observations*

Study	Instrument	Dimensions examined	Assessment method	# of observations[a]
Fennema et al. (1996)	CGI assessment instrument	4 dimensions regarding how often T's: 1. Invite S to problem solve 2. Invite S to share thinking 3. Elicit S thinking 4. Incorporate S thinking in instruction	T is assigned to a single level along a continuum from most to least cognitively guided (Level I – IVb)	2 per year, during the 3 PD program (6 total)
Luft (2001)	Extended Inquiry Observational Rubric (EIOR) (Luft, 1999)	8 categories that represent good science instruction and align with the 1996 NSES 1. Cooperative learning 2. T as guide 3. Assessment 4. S communication and action 5. Inquiry question 6. Designing and conducting an investigation 7. Gathering and analyzing data 8. Sharing of extended investigation	T is given a score for each category (1-5) 5 = the highest fidelity to extended inquiry program	Several taken at the midpoint and end of the PD program (specific number dependent on length of T's inquiry lesson)
Bell (2002)	Inquiry Assessment Tool (IAT)	11 categories adapted from the EIOR and essential features of inquiry (NRC, 1996) 1. Cooperative learning 2. T as guide 3. Assessment 4. Sci. oriented questions 5. Designing and conducting an investigation 6. Evidence as priority 7. Analyzing data 8. Formulating explanations 9. Justifying explanations 10. Communication 11. Use of mathematics	T is given a score for each category (1-5) 5 = the most oriented to inquiry	1 prior to, during, and after participation in PD program during a single academic year (3 total)
Blanchard et al. (2009)	Science Teacher Inquiry Rubric (STIR) (Bodzin & Beerer, 2003)	6 categories aligned with the essential features of inquiry (NRC, 2000) 1. Engagement with scientific questions 2. Development of a plan to gather evidence 3. Priority given to evidence 4. Formulation of explanations 5. Evaluation of explanations 6. Communication and justification of explanations	T is ranked along a continuum for each category (teacher centered to learner centered)	1 before and after the six-week PD program (2 total)

Note. T = teacher.

Table 2.2 (continued) *Comparison of Observational Methods Across Studies that Employed Classroom Observations*

Study	Instrument	Dimensions examined	Assessment method	# of observations[a]
Sherin & van Es (2009)	None	2 dimensions consistent with those encouraged in the PD program 1. Selective attention 2. Knowledge-based reasoning	Researchers sought confirming or disconfirming evidence of each dimension during 2 minute intervals of class	1 or 3 times early and late during the one year PD program (2 or 6 total)
Johnson & Fargo (2010)	Local Systemic Change (LSC) (Haney et al., 2002)	4 categories (each with subcategories) that reflect best practices as shared by the NSES and the NCTM 1. Lesson design 2. Lesson implementation 3. Classroom culture 4. Math/Science content	T is given a “synthesis” rating for each category (1-5) 5 = extremely reflective of best practice in math/sci education	1 per academic month during 2 year PD program (16 total)

Note. T = teacher.

Other researchers investigating teacher change in the classroom have employed instruments that require observers to locate aspects of a teacher's lesson and/or practice along one or more assessment-based continua. Blanchard, Southerland, and Granger (2009), for example, used the Science Teacher Inquiry Rubric (STIR), in conjunction with an analysis of teacher questioning techniques, to document change in teachers' instruction before and after their participation in the Marine Ecology for Teachers (MET) professional development program. The STIR requires an observer to classify six aspects of a teacher's inquiry lesson along a "teacher-centered - student-centered" continuum (Bodzin & Beerer, 2003). The six lesson features are aligned with the five essential features of inquiry published by the NRC (2000) and collectively reflect the extent to which a teacher is capable of implementing a student-centered inquiry lesson.

Fennema and her colleagues (1996) developed a similar "continuum" based observational instrument as part of the Cognitively Guided Instruction (CGI) project. Specifically, the CGI tool afforded researchers a means to assign observed teachers to one of four "levels" along the continuum based upon the degree to which aspects of their practice were cognitively guided (e.g. the degree to which teachers elicited student thinking and invited students to solve problems). The researchers then characterized changes in the teachers' "CGI levels" over time.

In contrast to other observational studies, Sherin and van Es (2009) did not incorporate a structured observational tool in their research design. Instead, Sherin and van Es elected to document types of "confirming or disconfirming" evidence for two components of teacher practice (selective attention and knowledge-based reasoning) during two-minute segments of observed classroom activity. Such evidence was grounded in the teacher's questions and statements directed towards students. The researchers utilized the findings from observations conducted early and late in the professional development project to describe how teachers' instructional practice changed along these two dimensions. In general, Sherin and van Es found that teachers improved in their ability to attend to and reason about students mathematics, albeit to different degrees, as they participated in video club professional development sessions.

An analysis of the research literature on teacher change shows that the primary objective of much of the empirical work to date has been to determine whether specific interventions are effective in promoting change in teachers' practice (e.g. Did the professional development program succeed in increasing the number of inquiry activities a teacher enacted in the classroom?). Few studies have been concerned with the nature of the change process itself (e.g. *How* and *when* did the change occur? What did the change *look like* over time?). Thus, while the methods of data collection and analysis typically selected (e.g. self-report surveys and/or numeric rubrics) have afforded researchers means to establish the *presence* of teacher change, they are somewhat limited in their ability to capture the *process* of teacher change.

Consider, for example, the research studies that have administered self-report surveys to collect data regarding teacher's instructional practice. Such methods are certainly capable of furnishing researchers with evidence as to whether a teacher incorporates more inquiry-based activities into their instruction following an intervention. These methods are limited, however, in enabling the researchers to make claims regarding changes in *how* the teacher implemented those inquiry activities in the classroom.

Research methods that utilize scoring rubrics are similarly constrained by their affordances and limitations. For example, assessment instruments may afford researchers means to document changes in teachers' reform-based practices as manifested in the classroom; however, such methods may be restricted in terms of enabling researchers to answer questions concerning how a teacher's *specific* instructional moves change over time. As mentioned earlier, such observational tools and rubrics tend to assign teachers a numeric score or place teachers along a continuum, based on the observers' overall impressions of the teachers' practice. Thus, there is little room to tailor aspects of the rubric to fit specific components of an individual teacher's practice and/or to reflect nuances that occur within a particular class session. Additionally, because researchers have tended to focus on whether a change happened, they have generally relied on a small number of observations scattered periodically over the course of the program to establish change. If researchers desire to characterize the details of the change process, more regular visitations to a teacher's classroom are required. More descriptive methods of analysis may also need to be identified and elaborated.

The research design employed by Sherin and van Es (2009) analyzed specific aspects of teachers' instructional behavior. By examining teachers' discourse, they were able to describe teachers' instructional practice along two dimensions: "selective attention" and "knowledge-based reasoning" (see section 2.3 for more on their methods). Ultimately, the researchers were able to use these descriptions to establish how the teachers changed in their instructional practice over the course of professional development. Blanchard et al. (2009) also investigated changes in particular features of teachers' instructional practice. In combination with the STIR, the researchers utilized

Bloom's taxonomy to assess the conceptual level of teachers' questioning to examine how teacher-centered the inquiry investigations were. The results from these analyses, in combination with results from interviews with the teachers, provided the means to characterize changes in teachers' instruction. Such methods of analysis are more amenable to describing the *process* of teacher change.

Situating Mrs. Miller's study of change

According to Blanchard et al., (2009), rich characterizations of the process of teacher change are only possible if researchers take part in prolonged engagement with the teachers and undertake rigorous methods of data collection and analysis. While these case studies are only capable of representing the change of a limited number of teachers, such descriptions provide a solid foundation for additional study into the process of teacher change.

The case study of Mrs. Miller extends and elaborates previous research on teacher change in several ways. First, previous studies on teacher change have varied in terms of time duration. Some reflect teacher change over a few weeks (e.g. before and after a short professional development intervention), while others reflect change over the course of a single term or academic year. Few have traced a teacher's change past one year (Fennema et al., 1996, Johnson & Fargo, 2010; Luft, 2001; McGregor & Gunter, 2006). Recent research has shown that reform-based change may take much longer to develop and become sustained in the classroom (Jacobs et al., 2010). In order to generate a richer characterization of the change process, longer case studies are necessarily required. The case study of Mrs. Miller describes her evolution in practice as she enacted inquiry over the course of three academic years.

Secondly, this case study utilized a large number of observations in order to describe a teacher's change. Specifically, this study involved daily observations of a teacher's instruction during three iterations of an inquiry-based module. In total, forty-three of Mrs. Miller's class sessions were observed, recorded, and analyzed, considerably more observations than have been utilized in previous research on teacher change.

Finally, this work has resulted in the identification of *a new construct* capable of isolating and characterizing a specific aspect of teachers' practice and describing teacher change. In this case study, the instructional strategy chosen was that of Mrs. Miller's practice of attending and responding to her students' thinking. The construct defined and elaborated in this study, the "redirection," affords researchers a means of describing *how* teachers attend and respond to their students' thinking. The following section of the literature review elaborates the instructional practice of attending and responding and provides justification as to why this practice was an appropriate focus for Mrs. Miller's case study.

2.3 Attending and responding to student thinking

Why study responsiveness?

Teachers attend and respond to different events in the classroom all of the time, as part of their ongoing professional activity. Events that might warrant a teacher's attention might be, for example, Tommy incessantly tapping his pencil in the back row, Suzi's furrowed brow and questioning gaze as she considers a problem on the board, or

Jamil's novel approach to investigating a curious phenomenon. Part of a teacher's expertise rests in their ability to recognize what is important in the sea of ongoing events and decide to respond in an appropriate way (Clark & Peterson, 1986).

When teachers attend to their students' comments in class, their focus is often on evaluating the "correctness" of the idea (Levin, 2008; Mehan, 1979). In this type of "directive" listening (Empson & Jacobs, 2008), the teacher attends to whether or not the student's comment is consistent with that which has been explained in class and responds according to her interpretation of the correctness of that idea. Recent reform documents have called for teachers to engage in a very different type of listening, however, that of attending and responding to students' *thinking* (AAAS, 1993; NCTM, 2000; NRC, 1996, 2001). This type of on-going formative assessment consists of teachers eliciting and interpreting their students' ideas about the problem task or activity during instruction and allowing these ideas to inform subsequent instructional moves that engage students to extend and/or elaborate their ideas (Black & Wiliam, 1998; Campbell, 1997; Franke & Kazemi, 2001; Jacobs & Ambrose, 2008).

Research has shown that teachers who elicit and use children's thinking as the basis for making instructional decisions positively affect student learning, as measured via researcher designed assessment instruments (Carpenter et al., 1989; Pierson, 2008; Ruiz-Primo & Furtak, 2007) and standardized tests (Carpenter et al., 1989). Pierson (2008), for example, found a significant correlation between teachers who exhibited a high level of responsiveness to their students' ideas (i.e. teachers that consistently "took up" their students thinking) and students' learning of mathematical concepts. Student achievement, in this study, was measured by an assessment tool developed by researchers and professionals involved with the large-scale SymCalc project. Carpenter and others (1989) similarly found that when teachers listened to students' problem solving strategies and generated instruction based on these strategies, their students tended to demonstrate deeper understandings of mathematics in comparison to students in the other classrooms, as determined via both standardized and researcher-designed assessments.

Unfortunately, the instructional practice of attending and responding to student thinking does not necessarily come easily to teachers. Teachers often require considerable support in order to become proficient in this type of activity (Empson & Jacobs, 2008; Jacobs et al., 2010). Studies of both novice and experienced teachers have demonstrated that, while teachers are certainly capable of attending and responding to their students' thinking, the development of these instructional practices may take years, rather then months (Fennema et al., 1996; Jacobs et al., 2010; Levin et al., 2009). How have researchers studied such practices? What is entailed for teachers to engage in attending and responding to their students' thinking? How do teachers develop expertise in this area? The following subsections provide a review of previous research that addresses these questions. First, I provide an overview of the different ways educational researchers conceptualize and empirically approach how teachers attend and respond to student thinking. I follow this section with a synthesis of the previous studies that have explored these instructional practices. I conclude with a brief discussion about how the results of this case study contribute to this growing area of research.

Conceptualizing how teachers attend and respond to student thinking

To date, the majority of research on how teachers attend and respond to student thinking has been conducted in the domain of mathematics education and has largely been affiliated with studies that have investigated teacher "noticing." Generally, the construct of noticing refers to what teachers pay attention to (i.e. "notice") in the stream of ongoing classroom activity and how they interpret and reason about those events. Possibly the most extensive work in this area has been carried out by Miriam Sherin and Elizabeth van Es (Sherin & Han, 2004; Sherin et al., 2008; Sherin & van Es, 2005, 2009; van Es & Sherin, 2002, 2006, 2008). These researchers, along with their colleagues, have decomposed the construct of noticing into three major components:

> *(a) identifying* what is important or noteworthy about a classroom situation; (b) *making connections* between the specifics of classroom interactions and the broader principles of teaching and learning that they represent; and (c) using what one knows about the context to *reason* about classroom interactions. (van Es and Sherin, 2002, p. 573, emphasis mine)

The first of these three components refers to *what* teachers notice in classroom activity. For example, a teacher watching a video from her class might identify a specific pedagogical move or a particular student idea as a significant event. Sherin and van Es (2009) refer to this skill as the teacher's "selective attention." The last two components of noticing listed above refer to *how* teachers interpret and reason about the events they perceive as significant. For example, when reasoning about a student idea, a teacher may restate the idea, or she may attempt to interpret the meaning of that student's idea. In later work, Sherin and van Es (2009) collapsed these two aspects of noticing under the collective heading, "knowledge-based reasoning."

According to these researchers' perspective, noticing exemplifies teachers' "professional vision," adapting Goodwin's (1994) framework for understanding how the members of a particular community view phenomena to the domain of teaching. Teachers necessarily notice and interpret specific features of their classroom, primarily as a result of their prior educational training and experience. As such, the ways they selectively attend to and reason about these features constitute their professional vision (Sherin, et al., 2008; Sherin & van Es, 2009; van Es & Sherin, 2008). The researchers contend that an important purpose of reform-based professional development should be to help teachers shift their professional vision toward selectively attending to and reasoning about their students' mathematical ideas.

Sherin, van Es, and their colleagues have conducted a number of studies exploring how teachers change with respect to what events/activities they identify as significant within video recorded classroom activity and how they reason about those significant events/activities. Findings from studies on experienced teachers suggested that participation in these so-called "video clubs" does foster change in *what* teachers notice (Sherin & van Es, 2005, 2009; Sherin & Han, 2004; van Es & Sherin, 2006, 2008). For example, teachers seemed to shift from a focus on pedagogical moves to a focus on student thinking. Related studies conducted on pre-service teachers have produced similar results (Sherin & van Es, 2005; van Es & Sherin, 2002); participants tend to focus more on student thinking over time. Additionally, the researchers found that novice and experienced teachers tend to change in *how* they noticed these events. Many participants shifted from simply describing student thinking to analyzing and/or generalizing about that thinking over the course of the program.

Star and Strickland's (2008) research on noticing corroborated Sherin & van Es' findings that even pre-service teachers can evolve in their ability to notice. The researchers' conceptualization of the construct was more narrow than that described above, however, restricting their focus to the first component of Sherin and van Es' characterization of noticing (i.e. individuals' ability to selectively attend to specific features of classroom activity). In their examination of how pre-service teachers changed with respect to *what* they noticed about recorded classroom activity, Star and Strickland found that their students developed the ability to attend to specific features of the classroom (e.g. the mathematical content of a lesson and/or the interactions between teacher and students), as they participated in a teacher education methods course.

In contrast to Star and Strikland's focus on the "*what"* component of noticing, Jacobs et al. (2010) explored the processes that underlie "*how"* teachers notice. First, the researchers identified a specific locus on which to concentrate their research efforts: teachers' professional noticing of children's mathematics. Second, they elaborated the construct of noticing to include three sub-skills: *attending* to children's mathematical strategies, *interpreting* children's mathematical understandings inherent in those strategies, and *deciding how to respond* based on their interpretation of the children's mathematical understanding[10]. Third, they investigated how teachers with different levels of classroom and professional development experience differed with respect to these three sub-skills.

In an extensive study of over 130 teachers, Jacobs and her colleagues provided participants with samples of children's thinking on mathematical tasks and asked them a series of questions regarding the children's mathematical strategies. These questions included asking teachers to describe what the children did, explain what they learned about the children's thinking, and discuss how they might respond to that thinking. The results of the cross-sectional study suggested that teachers developed the three aforementioned skills over time, but only when provided on-going professional support. Experienced teachers with no professional development fared as poorly as pre-service teachers with respect to how they noticed their students' mathematical thinking. The researchers also found that teachers seemed to develop noticing skills in sequence, with teachers first developing the ability to attend to students thinking, then interpret that thinking, and finally, potentially respond to that thinking.

Teachers' attending and responding to student thinking in the classroom

The context for the empirical work described in the previous section has been *outside* the classroom, either within specially designed professional development sessions or teacher education courses. Generally, these sessions consist of participants reflecting upon and discussing video clips of classroom activity, video segments of interviews with students, and/or images of student generated artifacts. As such, these aforementioned studies have focused more on exploring to what teachers *attend* in student thinking and, in the case of Jacobs et al. (2010), how they *might* respond. While these studies are important in providing the community with a deeper understanding about how and to what teachers attend, they do little to characterize how teachers' attend, and ultimately *do* respond, to their students' thinking within the classroom setting.

In a survey of the research literature, only a handful of studies have attempted to characterize teachers' practice of attending and/or responding to student thinking *in situ*.

Since it is methodologically challenging to make claims about the locus of teachers' attention during class, most researchers have elected to analyze teachers' discourse for indications as to the foci of the teachers' attention. Specifically, a teacher's *response* to his/her students is examined for signs as to his/her *attention*. Levin et al. (2009), for example, investigated how novice teachers changed in how they attended to their students' thinking as the teachers took a series of educational courses. In order to establish the locus of the teachers' attention, the researchers scrutinized teacher utterances for evidence as to how the teachers attended to their students' ideas. A teacher's response needed to include aspects of the *sense* of a student's idea from the student's perspective in order to qualify as evidence that the teacher was attending to her student's thinking. Levin and his colleagues did not consider responses that seemed to refer only to the correctness of student thinking as evidence of that kind of attention, however. Findings from their analyses indicated that most of the novices shifted their attention to focus more on student thinking over the course of an academic year.

Similarly, Sherin and van Es (2009) coded the general nature of teachers' responses to their students during two-minute increments of recorded classroom activity. These responses were evaluated for confirming and disconfirming evidence as to the locus of the teachers' "selective attention" (i.e. what events did the teacher respond to) and the extent to which the teachers exhibited knowledge-based reasoning (i.e. how, if at all, did they reason about their students' thinking). The results from the analyses suggested that teachers changed with respect to how they engaged with and reasoned about students thinking *in class* in a parallel fashion with how they changed in a "video club" professional development setting. The classroom findings provided evidence that participation in the video clubs may have informed teachers' instructional practice. Pierson (2008) analyzed teacher talk as a means to establish the extent to which teachers "took up" their students' thinking. She coded teachers' follow up responses according the degree of "responsiveness" the teachers demonstrated towards their students' ideas. She ultimately identified four levels of responsiveness: Low, Medium, High I or High II. The classifications reflected the nature of the teacher's focus (whether the teacher took up a student's idea or not) and whose reasoning on display (the teacher's or the students') as evident in the teachers' utterances. The teachers' responses that were coded as "High II Responsiveness" directly incorporated elements of the students' ideas and students' reasoning. In contrast, those that were coded as "Low Responsiveness" held limited connections to the students' thinking. Pierson ultimately found that students of teachers' that often issued "High II" responses were more likely to exhibit higher levels of mathematics achievement, as measured on assessments modeled after the Texas curriculum standards for seventh grade (TEKS – Texas Essential Knowledge and Skills) and the Texas Assessment of Knowledge and Skills (TAKS).

In addition to using teacher discourse as a means to establish the locus of teachers' attention in the classroom, Sherin and her colleagues (2008, 2011) also created a rather innovative method of uncovering teachers' attention. The researchers outfit a select group of mathematics teachers with "wearable" video cameras, which they wore on their heads as part of a baseball cap. The teachers were invited to record "interesting" classroom events as they unfolded during class. Such video recorded the events from the teachers' "point-of-view" and served to document events that drew the teachers' attention. [NOTE: These cameras featured “after-the-fact” technology, which enabled teachers to capture the previous 30 seconds of classroom activity.] The teachers were then asked to discuss *why* they considered the recorded classroom events to be “interesting.” While the researchers are still considering the conclusions that can be drawn from such technology, they posit that the cameras can illuminate specific aspects of teachers’ attention during classroom activity.

Mrs. Miller’s case study

This case study characterizing changes in Mrs. Miller’s responsiveness extends the attending and responding research literature in several ways. To date, there exist very few studies that have investigated how teachers change with respect to this dimension of their instructional practice *in situ*. Of those, one study has focused on changes in middle school mathematics teachers (Sherin & van Es, 2009), while the other has focused on changes of novice secondary science teachers (Levin et al., 2009). Hence, Mrs. Miller’s case study elaborates previous work by characterizing how an *experienced* science teacher changes with respect to how she responds to her students’ thinking.

Second, the studies that have previously examined teacher change in this area have only done so in the short-term (i.e. one year duration). While Jacobs and colleagues’ (2010) cross-sectional study provided evidence to suggest that teachers change in how they attend to their students’ mathematical thinking over the long term, their study did not examine this change in individual teachers. The case study of Mrs. Miller will be able to provide longitudinal data regarding how a teacher changes in how she responds to her students’ thinking over the course of three academic years. Thus, the findings can extend the short-term studies by providing a longer duration of investigation and potentially reinforce the findings of the cross-sectional study by providing longitudinal support.

Finally, researchers analyzing this dimension of teacher practice have relied primarily on qualitative discourse analysis as a means to describe how teachers attend and respond to student thinking (Levin et al., 2009; Pierson, 2008; Sherin and van Es, 2009). Part of the current study focused on isolating and characterizing a particular discourse move made by teachers during instruction (i.e. the "redirection") that reflected differing degrees of responsiveness. Thus, identifying and coding instances of this particular move affords researchers a means to add a quantitative dimension to the analysis of teachers' discourse.

This concludes the review of the literature that informed and situated this study. I now turn to a description of the study's research design and methodology.

CHAPTER 3: RESEARCH METHODS

This chapter presents the methodology used to describe Mrs. Miller's change across three successive implementations of an inquiry-based responsive curricular module. In the first section, I give a brief overview of the research design and describe the primary setting for the study: Mrs. Miller's classroom. In sections 3.2 and 3.3, I provide justification for choosing Mrs. Miller as a research subject and elaborate the context of the instruction: the LP water cycle curricular module. In section 3.4, I discuss the sources of data and methods of data collection, and in section 3.5, I outline the methods of data analysis and describe how these methods were aligned with the two overarching research questions. [NOTE: The first of the two questions was explicitly methodological in nature and concerned the development and characterization of a new method of analyzing teacher practice. It was one possible option to include a description of the finalized method here in chapter three. The developmental process turned out to be rather lengthy, however, and the resulting coding scheme is particularly complex. Hence, the presentation and description of the new method of analysis seemed to warrant its own chapter (see Chapter 4).]

3.1 Overview of the research design

The focus of this work was on Mrs. Miller's practice *during* instruction; thus, video recordings of classroom sessions served as the primary data source. These recordings captured the talk, gestures, and body language of Mrs. Miller and her students, as well as aspects of the various activities (e.g. discussion, experimentation, journaling) in which they were engaged during class.

As mentioned previously, the particular aspect of Mrs. Miller's instructional practice in which I was most interested was her responsiveness to student thinking. Through careful and systematic analysis of the classroom discourse[11], I was able to identify a type of move that Mrs. Miller regularly made (a "redirection") that seemed to reflect varying levels of responsiveness to her students' ideas. Analyses of these redirections afforded a means of describing Mrs. Miller's classroom practice and generating claims of change over time.

Data collected outside of the classroom, specifically via recordings of interviews and professional development sessions of which Mrs. Miller was a part, supplemented the video recordings of the class sessions. These external sources provided additional support for claims of Mrs. Miller's change in practice. For example, Mrs. Miller's comments during debriefing sessions gave insight into what she noticed in her students' thinking and why she made some of her "in-the-moment" decisions during class. These comments served to reinforce observations of her classroom practice.

In the sections and subsections that follow, I clearly delineate each of the different sources of data and methods of data collection and analysis for the study. I first revisit why Mrs. Miller represented a worthwhile candidate for research.

3.2 Why study Mrs. Miller?

Mrs. Miller is a national board certified elementary school teacher with more than twenty-five years of teaching experience at both the elementary and middle school levels.

She has served as a mentor teacher for student teachers and those in their first years of teaching for many years. Unlike many elementary teachers (Tilgner, 1990), it is clear that Mrs. Miller has historically felt comfortable teaching science to students. Early in the project, Mrs. Miller expressed great confidence in her knowledge of science, likely due in part to her advanced degree in microbiology. She even referred to herself as “the science expert” when addressing her fellow LP teachers [October 22, 2008, teacher meeting]. She also reported being regularly praised by her administrators as an excellent science teacher and mentor (August 13, 2010, summer workshop).

When Mrs. Miller first joined the LP project, she expressed hesitation and frustration at the thought of implementing pedagogy so drastically different from her more traditional style of teaching science. On the second day of the initial summer workshop she stated, “I still have to come back to theory and reality. I have two [colleagues] who, after yesterday, they don’t even want to come back [to the LP workshop]. They’re so frustrated because of the [project’s] demands put on us” [August 19, 2008, summer workshop]. Mrs. Miller’s conception of science instruction, at that time, seemed to focus on setting highly structured tasks for students and holding them accountable for carrying out those tasks. Thus, allowing student ideas to dictate the direction for subsequent instruction was somewhat foreign to her. When presented with a clip of a discussion taken from another teacher’s science class and asked how the teacher could have responded to the students’ ideas, she stated, “Where might the teacher go? … What is it that I wanted them to get from this? I would need to clarify with the kids again what I wanted them to get out of it. Redirect them back to the original task” [October 22, 2008, teacher meeting]. Rather than placing the student ideas as the subjects of further inquiry, Mrs. Miller seemed to favor adhering to a strictly structured, content standards-driven agenda.

Within several months of working with the project, however, Mrs. Miller seemed more amenable to the novel approach to science instruction. After implementing an activity consistent with the LP "responsive" format, she seemed excited and somewhat surprised that her students were capable of engaging in rich, substantive discussions about natural phenomena without her having to impose heavy structure upon them. She expressed amazement that her kids could work for an hour exploring and elaborating their observations of salt dissolving in water. Mrs. Miller stated that she was impressed with the students' sense of "empowerment" when they engaged with scientific phenomena in that setting [January 2009, interview]. The fact that these rich discussions occurred without much prompting and without her having to "spoon-feed them vocabulary" enhanced Mrs. Miller's initial willingness to implement the responsive, inquiry-based water cycle module during the spring of 2009.

As an experienced teacher implementing a new type of teaching curriculum/strategy, Mrs. Miller was an excellent candidate for study. She expressed interest and enthusiasm for aspects of the LP's pedagogical approach. In particular, she was interested in making more room for her students to engage with, discuss, and explain natural phenomena. Yet, Mrs. Miller had worked hard to cultivate her primarily content driven science instruction over 25 years, the latter fifteen of which had centered around the heavily scripted Full Option Science Systems (FOSS) curricular materials (Lawrence Hall of Science, 2007). The tension between implementing an inquiry-based, responsive module and her extensive experience with more directive science instruction provided a rich context from which to study her change in practice, both in the short term (within a single module implementation) and longitudinally (across three successive implementations).

3.3 Context of instruction: The water cycle module

The context for this study was an inquiry-based instructional module on the water cycle, one of several curricular modules developed by the Learning Progressions for Scientific Inquiry (LP) project. The module was designed to provide teachers a generative context (in this case, the water cycle) with which to explore and promote student inquiry practices (see below for a description of such practices). This type of module exemplifies a *responsive* curriculum, as conceived by the LP project; it affords a teacher a means to be responsive to her students' ideas about the water cycle, allowing the ideas to become the objects of inquiry from which to build upon and expand during subsequent instruction. It does not contain any pre-packaged lesson plans nor does it include any specific guidelines as to which classroom activities to do in which order. Furthermore, the module does not provide the teacher with prescribed learning outcomes or content understandings that the students need to achieve by module end. Rather, the module's design allows for the elicitation of student ideas about particular phenomena and makes space for those ideas to be considered, investigated, expanded upon, and elaborated by those in the classroom community.

The water cycle module begins by having the teacher pose an initial open-ended question for the purpose of stimulating discussion among students[12]:

> Suppose that one night it rains. When you arrive at school, you notice that there are puddles of rainwater in the parking lot. When you go home, you notice that the puddles are gone. What happened to the rainwater?

The students are then encouraged to suggest reasonable answers to this question and consider *why* such answers are plausible. The minimal curricular materials provide several possibilities as to the student ideas that might emerge through discussion, as well as several *potential* follow-up questions and/or discussion topics. These follow-up options may or may not be deemed appropriate by the teacher, depending on the student ideas that shape the initial (and subsequent) discussions. Ultimately, the teacher *chooses* which directions to pursue, ideally basing his/her instructional moves primarily on the substance of the students' ideas. The teacher can opt to go down one of several pathways depending on the comments of his/her students. The goal of such an open-ended, responsive format is to encourage the students' inquiry practices of making sense of and reasoning about scientific phenomena, proposing plausible, mechanistic explanations of those phenomena, and, if appropriate, collecting evidence to support or refute these explanations.

3.4 Sources of data and methods of data collection

There were four sources of data for this study: (a) Mrs. Miller's classroom during the implementations of the water cycle module, (b) one-on-one debriefing sessions with Mrs. Miller immediately following the classroom sessions, (c) additional one-on-one interview sessions with Mrs. Miller, and (d) professional development (PD) sessions of which Mrs. Miller was a part. I describe the data collection methods that were employed for each of these data sources in the subsections below.

Data source A: Mrs. Miller's class sessions

As mentioned in section 3.1, Mrs. Miller's class sessions during the three implementations of the water module served as a primary source of data for this study. Data was collected during the academic years of 2008-2009, 2009-2010, and 2010-2011. Each module implementation took between 13 and 15 hours of class time and served as a replacement for Mrs. Miller's FOSS® science lessons on the water cycle (Lawrence Hall of Science, 2007). The individual instructional sessions tended to last for approximately sixty minutes and took place two to four times per week for the duration of the implementations. Data from this source was collected via video recording, field notes, and classroom artifacts, each of which is described below.

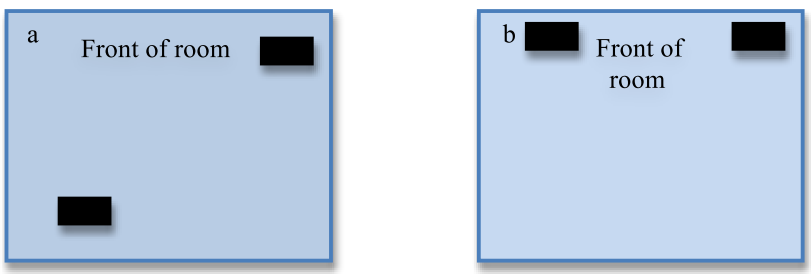

Figure 3.1 *Placement of Video Cameras in Mrs. Miller's Classroom.* (a) Camera arrangement during spring 2009 implementation. (b) Camera arrangement predominantly used during the fall 2009 and fall 2010 implementations.

I. **Video recordings:**

- During the three implementations, each class session was video recorded in entirety via two video cameras, each with a wide-angle lens[13]. These cameras were strategically placed in order to capture as much of the classroom activity as possible (see Figure 3.1) and were operated *in situ* by a cameraperson who focused on one or more individual speakers (student and/or teacher) during class discussions and activities. During group work, one camera followed Mrs. Miller around the room, while the other was directed on one "focal" group of students. The cameras scanned the class and occasionally zoomed in on individual students during individual seatwork.

- For the first implementation of the module, the cameras were arranged such that one camera recorded at the front, while the other filmed from the back of the room (Figure 3.1a). This arrangement, however, seemed to be less than optimal for capturing the faces of the students. As a result, both cameras were placed towards the front of the room during the second and third implementations (Figure 3.1b).
- To enhance audio input, Mrs. Miller was given a wireless lavaliere microphone to attach to her lapel. A second lavaliere microphone was alternately positioned above the students' heads in the center of the room (during whole class discussions) and on the focal group's table (during group work).

II. **Field notes:**

- Detailed field notes were taken during every class session throughout the three implementations. Field notes provided an excellent means of tracking the topics of conversation during instruction and afforded me a means to keep track of thoughts/ideas I had during the instruction (e.g. marking interesting events, noting instances of particular behaviors). In addition, these notes helped me to identify specific class segments to discuss with Mrs. Miller during debriefing sessions.

- The initial notes were hand written, rather than electronic, since I concurrently operated a video camera during class sessions. The field notes were later summarized and indexed electronically, resulting in a comprehensive field note repository that was used during analyses.

III. **Classroom artifacts:**

- All drawings and/or writings generated by Mrs. Miller and/or her students during class (either at the front board or at the students' desks) were captured via digital stills directly following each class session.
- Electronic scans were made of the students' science journals at the conclusion of the module implementation. The science journals consisted of collections of individual students' class work, notes, and homework completed during the module.
- Mrs. Miller often recorded student ideas as they emerged during discussion, as well as her thoughts regarding future instructional activities. Electronic scans of all of these notes were made at the end of the module implementations.

Data source B: Debriefing sessions with Mrs. Miller

Debriefing sessions were one-on-one interview sessions that occurred immediately following class instruction. The interviews consisted primarily of Mrs. Miller and I discussing what we had noticed in the students' ideas during the class, our overall impressions and thoughts about the class, and our thoughts about the next session's activities. Over the course of the three implementations, I tended to offer fewer of my own suggestions and encouraged Mrs. Miller to take a larger and larger role in the planning and preparation of future class activity. The debriefing interviews took anywhere from five to fifteen minutes in length, depending upon Mrs. Miller's schedule and the nature of the class discussions/activities that day. Data from this source were collected via audio recordings and field notes.

I. **Audio recordings**:

- While some of the early debriefing sessions during the spring 2009 implementation were captured on video, it was not feasible to continue this practice, since the sessions often took place during mid-morning recess when Mrs. Miller had playground duty. As a result, a digital audio recorder was employed to capture conversation for the majority of the three implementations. Audio recordings were capable of reproducing Mrs. Miller's intonation and emphasis in addition to her talk, which seemed more than sufficient for the purposes of this study.

II. **Field notes:**

- Field notes were created soon after each debriefing session. These notes both summarized the content of the session and served to capture my impressions of the interaction. Electronic transcriptions of these notes were added to those taken during the actual class sessions and were included in the comprehensive electronic repository described above.

Data source C: Interviews with Mrs. Miller

Additional interviews with Mrs. Miller enabled me to collect data regarding her thoughts, beliefs, and goals about the teaching and learning of science in an informal and relaxed (e.g. non-instructional, less immediate) setting. These sessions consisted of general discussions about her classes, as well as specific discussions about events that occurred during class. In some of these interviews, I played pre-selected video segments taken from her classroom, which provided a context for discussing specific student ideas and/or to highlight specific classroom events for stimulated recall (e.g. Clark & Peterson, 1986; Schoenfeld, 1998). Topics of conversation during these discussions included Mrs. Miller's general impressions of the video segments, her thoughts about her students' participation, her feelings about her role during the instruction, and reasons underlying specific decisions she had made during the video clips. Data from this source was collected via video recordings and summary reports.

I. **Video recordings:**

- These interviews were video recorded in entirety, allowing for transcription and subsequent content analysis.

II. **Summary reports:**

- Summaries were written soon after each session. These notes synthesized the content of the interview and served to capture my overall impressions of the session. Electronic transcriptions of these summaries were included in the electronic repository.

Data source D – Professional development sessions

Mrs. Miller was an active participant in the long-term professional development (PD) sessions associated with the Learning Progressions for Scientific Inquiry (LP) project. Her involvement consisted of her taking part in weeklong workshops during the summers of 2008 and 2010, a two-week workshop in the summer of 2009, and bi-weekly meetings during the 2008-2009, 2009-2010, and 2010-2011 academic years. These PD sessions provided opportunities for Mrs. Miller and other in-service elementary and middle school teachers to practice attending and responding to student thinking, with the explicit intent of helping them develop their ability to promote rich student scientific inquiry in the classroom. The teacher "learners" engaged in a variety of activities, including: (a) watching segments of classroom video (both their own and those of other teachers), (b) characterizing and assessing the "scientific merit[8]" (i.e. instructional value) of student ideas, (c) engaging in scientific inquiry, (4) reasoning about natural phenomena, and (5) journaling about their experiences in the project (instructional and otherwise). These activities gave the teachers experience attending to student ideas, proposing meaningful responses to student ideas, as well as doing, and reflecting upon, science themselves, all in the service of helping the teachers to learn how to promote more effective scientific inquiry in their classrooms. Data from this source were collected via video recordings, field notes, and artifacts.

I. **Video recordings:**

- These PD sessions were video recorded in entirety, allowing for subsequent content analysis.

II. **Field Notes:**

- Various members of the LP staff generated field notes during the professional development sessions. These notes primarily summarized the content of the session and helped to index the video recordings of the sessions.

III. **Artifacts:**

- Occasionally, the PD sessions involved writing activities (e.g. observations, reflections, case studies). All of Mrs. Miller's written documents were collected for content analysis.

3.5 Methods of Data Analysis

The primary data stream for this study was the video recording of Mrs. Miller *in situ*. These classroom video data were transcribed and captioned in entirety to permit careful scrutiny of Mrs. Miller's talk and co-occurring body language during all class sessions of the water cycle module implementations. Analyses of these video sessions proceeded in two phases (i.e. Phase I and Phase II), each of which consisted of a sequence of different stages. The following two subsections provide an overview of these two phases of data analysis.

Prior to continuing, it is important to note that only segments of whole class discussion were subjected to Phase I and Phase II analyses. The decision to use whole class discussions was made for three reasons. First, limiting the analyses to segments of whole class discussion narrowed the data corpus (over forty-three hours of instructional time) to a more manageable set of data (approximately twenty-eight and a half hours of instructional time). Second, other researchers who study teacher practice *in situ* have elected to focus primarily on segments of whole class discussion or large group discussion (e.g. Franke, Webb, Chan, Ing, Freund, & Battey, 2009; Sherin & van Es, 2009). Hence, there was precedent for this type of decision. Lastly, there were occasions where video and/or audio recordings of Mrs. Miller's interactions with her students during small group or individual work were of low quality or simply unavailable. Thus, the discourse analyses concerned only those segments of whole class discussion.

Phase I: Development of a new method of analyzing teacher practice

There were two main objectives underlying Phase I, each of which was aligned with one of the two overarching research questions guiding this study. For discussion purposes, I reproduce these two research questions here:

Within the context of endeavoring to teach science as inquiry in the classroom:

(1) How can a teacher's responsiveness to student thinking be characterized?

(2) How does one teacher, Mrs. Miller, change with respect to her responsiveness to student thinking over the course of three iterations of an inquiry-based module?

The first objective of Phase I, which was aligned with research question #1, was to develop a new means of analyzing teacher practice. The second objective, which was aligned with research question #2, was to utilize that means to analyze Mrs. Miller's practice over three iterations of the water cycle module. Figure 3.2 displays the sequence of four stages that ultimately comprised Phase I.

To generate a new method of analyzing teacher practice, it was necessary to first identify criteria by which to judge whether a particular method of analysis was appropriate for the case study (see Figure 3.2, Stage I). Two such criteria were distinguished. First, the successful method of analysis had to be of sufficient grain-size to distinguish a specific aspect of Mrs. Miller's classroom practice that reflected her responsiveness to her students' ideas. Second, the method had to represent a vehicle by which to richly and productively capture *how* Mrs. Miller's practice changed along this dimension over the three implementations of the water module. An effective method of analysis would necessarily have to fulfill both criteria.

Once these two criteria were established, I engaged in a thorough examination of previous educational research studies in the areas of teacher practice and change (see Figure 3.2, Stage II). Specifically, I focused my attention in the following overlapping research strands: (1) studies that characterized dimensions of teacher change either in or out of the classroom, (2) studies that explored and/or assessed aspects of reform-based math or science teaching practice, and (3) studies that investigated teacher responsiveness. This review of the research literature enabled me to generate a deeper awareness of what had been done previously and helped me to identify elements of other methods of analysis that seemed amenable to Mrs. Miller's case study. Since several of these studies are further elaborated in Sections 2.2, 2.3, and 4.1, I do not discuss them further at this point.

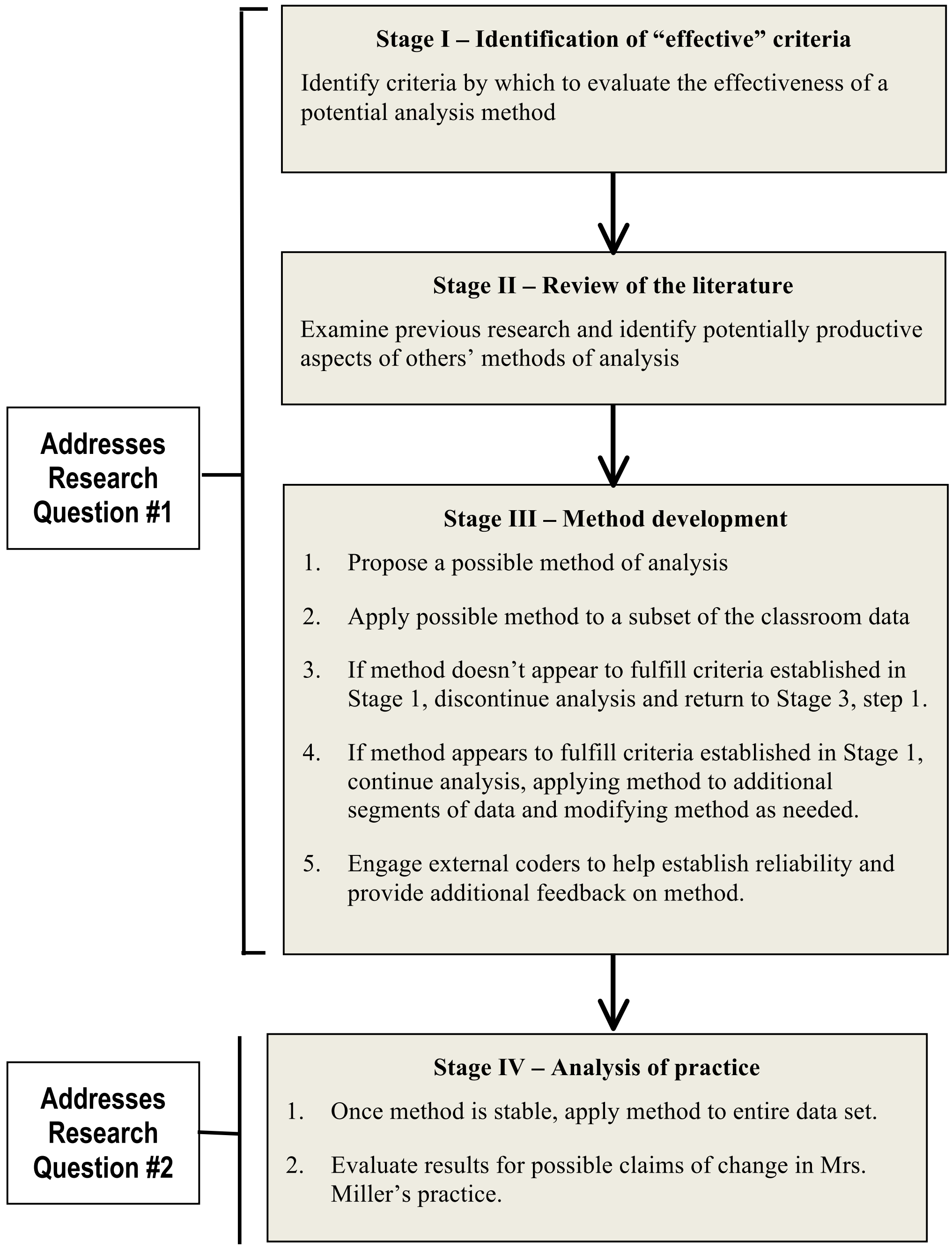

Figure 3.2 *Phase I of Data Analysis.*

An evaluation of previous work, in conjunction with my familiarity with the data itself, allowed me to propose a few methods of analysis that held potential (see Figure 3.2, Stage III), including the characterization and tabulation of Mrs. Miller's individual responses to her students and the generation of descriptions of Mrs. Miller's lengthier "probing sequences" (see section 4.1 for additional descriptions of these two preliminary methods). These methods of analysis were individually applied to a subset of Mrs. Miller's classroom data and were later dismissed, since they did not meet the criteria established in the first stage of Phase I. Specifically, these methods were incapable of detecting change in Mrs. Miller's practice, as Mrs. Miller tended to probe her students' responses with similar frequency and length, and in a similar manner (i.e. asking for clarification and/or elaboration) during implementations one and three.

The process of applying the preliminary, yet unsuccessful, methods of analysis led to the eventual identification of a method of analysis that did meet both criteria: the examination and characterization of Mrs. Miller's redirections (see Chapter 4 for full description of this construct and its associated coding scheme). Once the redirection construct was used successfully to analyze a small subset of data, it was applied to additional segments of classroom data and modified as necessary. This began an iterative cycle of construct application and modification, with successive versions of the scheme being generated, subjected to the data, and modified accordingly. External coders were invited to examine and apply the coding scheme to portions of the data at several points during the process, in order to help establish the validity and reliability of the construct (see Section 4.5). Eventually, a stable construct and coding scheme emerged, as a result of the constant comparison between the construct and increasingly larger sets of data (Strauss, 1987) and the feedback provided by external coders.

The second objective of Phase I was to use the newly developed and stable method to analyze the entire data set. Thus, Stage IV of Phase I applied the redirection construct to the video recordings of Mrs. Miller's practice over the course of the three implementations. The results of this analysis were subsequently quantitatively and qualitatively examined for patterns from which to base claims of change in Mrs. Miller's practice (see research question #2). The results of these analyses are presented and discussed in Chapter 5.

Phase II: Phenomenological description of teacher change

Although the development and application of the redirection construct proved to be effective in describing change in Mrs. Miller's responsiveness, it represented a means to capture only one aspect of Mrs. Miller's practice. Such a method of analysis was somewhat limited in comprehensively capturing how Mrs. Miller changed with respect to her inquiry-based instruction. Phase II of data analysis was designed to move beyond possible limitations and/or constraints inherent in the aforementioned method by employing a phenomenological approach (van Manen, 1990) in describing Mrs. Miller's practice. Specifically, Phase II would entail a detailed description of interesting and seemingly relevant elements of Mrs. Miller's instructional practice as defined by the research questions. The objective of the second phase was to extend the previous analyses of Mrs. Miller's redirections by examining a subset of the classroom data in a more holistic manner. The result of such analyses would be a richer picture of Mrs.

Miller's change in responsiveness to her students' thinking and provide an additional layer to Phase I's response to research question #2.

Phase II consisted of two basic stages (see Figure 3.3). The purpose of stage I was to identify "events" or "phenomena" that similarly occurred in each of the three implementations. This identification of such events would allow for the comparison of Mrs. Miller's practice across implementations. Ultimately, two events were selected. The first event was the initial class session of each of the three module implementations or "Day 1." Since all three modules began with a similarly phrased launching question concerning a disappearing puddle, an examination of Mrs. Miller's practice on Day 1 seemed a reasonable method to compare Mrs. Miller's inquiry-based practice across time. The second "event" occurred towards the end of each of the three modules (Day 11 or later) and consisted of the whole class discussions and activities that took place around the phenomenon of water dripping off a plastic bag filled with ice. Although the circumstances in which "Ice Bag" arose and the manner in which the event unfolded varied from implementation to implementation, the phenomenon of the dripping ice bag was the focus of attention for an large portion of one or more class sessions during each of the three module implementations. Thus, the Ice Bag event seemed to be a good context for additional examination of Mrs. Miller's practice over time.

For each of the two identified events, video recordings of the appropriate sessions were carefully scrutinized and generally described for each implementation (Stage II). Then, Mrs. Miller's instructional practice during the event was further examined along several dimensions, some of which were aspects similarly explored in previous studies of teacher practice (e.g. Blanchard et al., 2009; Franke et al., 2009), including: her questioning strategies (e.g. types of questions asked, frequencies at which she asked them), facilitation moves she made during the event, and how she brought the discussions/activities to an end. The resulting descriptions of Mrs. Miller's practice during the two events were then compared across implementations, in order to generate claims about her overall change in practice. Chapter 6 further elaborates these analyses and discusses the results.

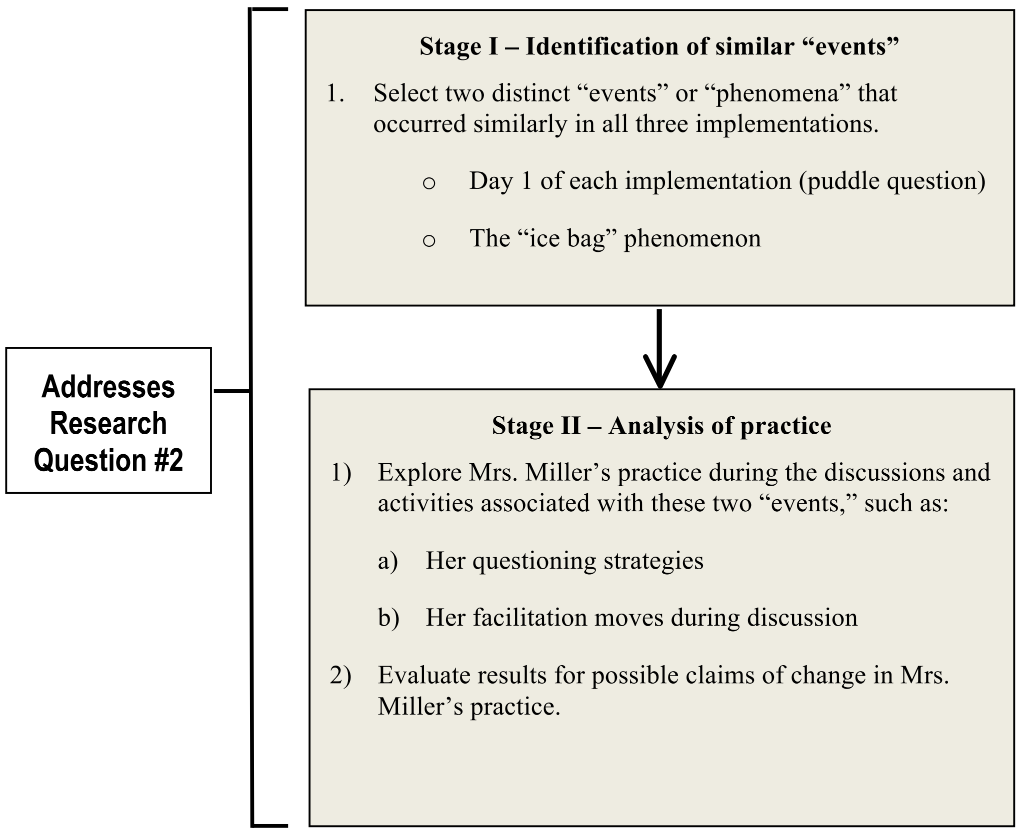

Figure 3.3 *Phase II of Data Analysis.*

I now turn to presentation and characterization of the redirection construct and coding scheme.

CHAPTER 4: REDIRECTIONS

As with the development of any new analysis tool, the characterization of the redirection construct was neither simple nor straightforward. There were many false starts and dead ends. Different codes evolved as a result of iterations moving between prospective categories and classroom data. Through the method of constant comparison (Strauss, 1987), tentative codes were modified and became more stable or were dismissed. Eventually, a comprehensive coding scheme emerged. The follow sections describe the process by which the construct was identified, present the current form of its associated coding scheme, and discuss the methods by which inter-rater reliability was sought.

4.1 Developing a new construct

As discussed in Section 2.2, there are several methods that have been used to characterize elements of teachers' instructional practice. When assessing teachers' practice *in the classroom*, researchers have tended to utilize observational "protocols" with standardized rubrics, requiring observers to assign one or more scores along a variety of dimensions or categories of practice. The Science Teacher Inquiry Rubric (STIR), for example, requires observers to rank lessons along six "dimensions" of practice across a continuum from teacher directed to student directed (Bodzin & Beerer, 2003). The focus of this type of protocol is assessing a teacher's general instructional strategies, such as evaluating the degree to which a teacher encourages her students to generate and work with their own scientific questions. This type of rubric does not explicitly investigate facets of a teacher's practice that underlie such broad strategies, however. Similarly, the Extended Inquiry Observation Protocol (EIOR) requires observers to assign numeric scores along eight "categories," collectively reflecting the degree to which teachers engage in "sound scientific instruction" (Luft, 1999). These categories are primarily phrased in terms of the activities in which the students engage in the classroom (e.g. student communication and action), although some general teacher strategies are listed (e.g. teacher acts as guide). As with the STIR, the focus of EIOR is not on teasing out a teacher's individual instructional moves. Rather, the EIOR permits exploration of general characteristics of student and teacher activity during an inquiry session.

The abovementioned rubrics, as well as other "reform-based" observational tools like the Reformed Teaching Observation Protocol (RTOP) (Sawada, Piburn, Judson, Turley, Falconer, Benford, 2000) and the Local Systemic Change protocol (LSC) (Haney et al., 2002), are structured in such a way as to enable observers to capture general aspects of classroom activity. Such protocols typically result in "synthesis" scores that reflect an average across the entire instructional session or mark the presence/absence of general instructional activities or strategies. While such numeric protocols may afford the ability to: (1) evaluate a teacher's implementation of a specific instructional strategy, (2) compare large numbers of teachers across general strategies of practice, or (3) detect the *presence* of a change in a teacher's practice (e.g. Is there a change in practice?), these protocols may be less capable of enabling researchers to capture and describe the *process* of change (e.g. How does change happen? What does change look like?). Hence, these numeric protocols seemed to be of limited use for the purposes of this study.

In contrast to painting observations in broad strokes, a few studies of teacher practice and/or teacher change have employed finer-grained analyses of classroom instruction. While these methods often require more time and effort during data collection and analysis, they afford researchers a means to capture specific aspects of a teacher's classroom practice. Sherin and van Es (2009), for example, broke up classroom sessions into two minute segments and coded each segment with respect to two specific features of a teacher's practice: selective attention and (mathematics) knowledge-based reasoning. These coded segments ultimately provided a means by which the researchers could compare the teacher's practice pre/post a professional development intervention.

Rather than coding segments of data, others have elected to code *instances* of specific teacher and/or student activity. In their work examining mathematics teachers' practice, Fraivillig, Murphey, and Fuson (1999) developed a pedagogical framework delineating specific teacher moves that supported children's mathematical thinking. This framework was used to establish the frequency at which various teachers utilized each of these instructional moves in the classroom. Rather than analyzing multiple elements of a teacher's practice, Franke and her colleagues (2009) elected to examine one dimension of instructional practice, that of a teacher's questioning technique. By analyzing classroom discourse, they were able to draw conclusions regarding the effect different types of teacher follow up questions had on students' responses. Blanchard and colleagues (2009) also employed fine-grained discourse analysis, examining instances of both teacher and student questions. In their study, the researchers coded questions according to who initiated the question, whether the question pertained to relevant content, and its placement on the revised Bloom's taxonomy scheme (Huitt, 2004, as cited in Blanchard et al., 2009).

In order to evaluate whether a method of analysis was appropriate for this case study, it was first assessed as to whether it met two criteria. First, the method had to be able to detect a dimension of Mrs. Miller's practice that reflected her responsiveness to her students. Second, the method had to represent a vehicle by which to capture *how* Mrs. Miller's practice changed along this dimension over the three implementations of the water module. An approach similar to that adopted by Franke et al. (2009) and Blanchard et al. (2009) appeared to fulfill both of these criteria. The identification and description of instances of teacher activity seemed to be an appropriate grain size by which to characterize specific aspects of Mrs. Miller's practice. In particular, a focus on Mrs. Miller's verbal responses to her students held potential in terms of exploring the extent to which she took up her students' ideas. Furthermore, an examination of these responses over time seemed to be a method capable of characterizing Mrs. Miller's change.

During the preliminary stages of analysis, I selected several class periods from the first and third implementations in order to evaluate whether describing an aspect of Mrs. Miller's follow up responses might prove to be fruitful for analysis. (While it is certainly arguable that change is not linear, I considered Implementations 1 and 3 to be far enough removed from one another to likely reflect differences in Mrs. Miller's practice. This consideration was consistent with what I my intuition said to be the case, having been present in Mrs. Miller's classroom throughout the three implementations.) I identified different categories (e.g. questions, statements, acknowledgements) and subcategories (e.g. general questions, clarification questions, elaboration questions) of responses and tabulated the frequency at which Mrs. Miller employed each type of response. Unfortunately, this method of analysis proved unproductive, as Mrs. Miller appeared to use similar types and frequencies of responses across sessions and implementations.

I then turned my attention to longer segments of talk that included teacher-student interactions with at least one teacher follow-up prompt, similar to the probing sequences analyzed in Franke et al. (2009). I coded each segment according to length (# of follow up responses) and types of responses (e.g questions, statements, acknowledgements) made by Mrs. Miller. Again, this method did not seem to be a productive means to capture change in Mrs. Miller's practice, since sessions from implementations one and three appeared to yield similar results.

Through these preliminary rounds of classroom analysis, I became increasingly aware of instances where Mrs. Miller made attempts to shift the attention of her class from one locus to another. At times, these bids seemed to reflect a high level of responsiveness, as when Mrs. Miller invited her class to consider or reason about a specific student's observation or explanation. On other occasions, however, she seemed to shift students' attention to a locus that seemed completely unrelated to previous student comments/ideas. Collectively, these attempts to move the class's attention from one locus to another seemed to constitute a dimension of Mrs. Miller's practice that could be identified, characterized, and used to trace change across time. Analysis of selected days from implementations one and three also suggested that characterization of these moves could prove productive, in terms of depicting a change in Mrs. Miller's practice. The name adopted for this element of Mrs. Miller's practice, specifically the "redirection," was grounded in Mrs. Miller's own words. In the middle of a discussion, Mrs. Miller stated that she wanted to "redirect" her students back to focus on the initial question for the day, "What causes rain?" [Year 1, Day 10].

Through iterative cycles of developing categories of redirections, comparing them to the discourse data, making appropriate alterations, and returning to the data, a scheme was constructed that characterized redirections according to nature of the attempted shift and the type of responsiveness suggested by such bid. Early versions of the coding scheme were provided to four coders, each of whom was also given multiple segments of data to examine and code. The feedback provided by these coders proved to be an invaluable part of developing the finalized coding scheme. In the following three sections, I present and exemplify the finalized redirection construct and its associated coding scheme. The final section of the chapter will provide inter-rater reliability results.

4.2 Presentation and explanation of the redirection construct

Defining the construct

I define a redirection as Mrs. Miller's bid to shift, refocus or redirect the attention of the class from one scientific phenomenon/question/activity to another. A redirection consists of a question or comment submitted by Mrs. Miller to her class that stops the ongoing flow of her students' work and attempts to shift their course either by presenting an alternative (scientific) locus for her students' attention or by prompting her students to engage in a new (scientific) activity. Such bids are regularly evident by Mrs. Miller's verbal behavior (e.g. choice of words, voice inflection and tone) and/or her co-occurring non-verbal behavior (e.g. body movement, gesture, facial expression), which clearly indicate that she would like her students to consider the new topic or change activity. A redirection represents Mrs. Miller's bid to shift the attention of the class; the students may or may not necessarily take up this bid for additional discussion/activity. Hence, the shift need not be successful for an attempt to be considered a redirection.

Most redirections are questions posed to the entire class and are usually concurrent with distinct changes in Mrs. Miller's body language. For example, Mrs. Miller usually issues redirections in a loud voice, while she sits up in her chair, scans her students' faces, and gestures expansively. Occasionally, Mrs. Miller's redirections are directed to a single student rather than the whole class, however. These redirections can be recognized as instances where Mrs. Miller asks a student other than one whom she had previously engaged to comment on something specific (e.g. explain a scientific term or elaborate another student's comment). While such invitations are directed to a single student, they serve to highlight a new topic as the focal point for both the invited student and the rest of the class for consideration and discussion.

In order for a question or comment to be identified as a redirection, the talk turn must be related to science. Hence, a comment or question that is disciplinary or related to housekeeping would not be considered to be a redirection. A redirection must, by definition, be a bid for her students to consider a new scientific topic or activity. Additionally, the question or comment must allow space and time for the students to respond. A question asked rhetorically and/or without time for comment would, therefore, not be considered a redirection.

For the purpose of this study, a follow up question that prompts a student to clarify or elaborate his/her thoughts within an ongoing dialogue does not constitute a redirection. The reasoning behind this is that it is not possible to definitively determine whether Mrs. Miller intends the outcome of such a follow up question to be the focus of attention for the entire class. Instead, such prompts may only reflect Mrs. Miller's desire to understand and/or extend a student's ideas within their ongoing exchange, serving as facilitation moves to perpetuate the current course of conversation. Additionally, Mrs. Miller's statements made at the end of an exchange, where she parrots her student's comments without clearly placing them up for class consideration, are considered to be acknowledgements rather than redirections. If, however, Mrs. Miller concludes an exchange by turning to her class and broadcasting a topic publicly, then that broadcast would constitute a redirection.

To illustrate the difference between an acknowledgement and a redirection, compare the following two situations. In the first case, Mrs. Miller follows a student's explanation that a puddle of rainwater might have "drained into the sewer" by nodding her head and repeating the explanation verbatim. She does not raise her voice nor does she scan the other students' faces, rather she simply makes a note of the student's comment in her notebook (see Figure 4.1a). This response would be considered an acknowledgement only, for there is no indication that she intends for her class to consider this explanation in the next segment of discussion. If, however, the same student's comment was followed by Mrs. Miller raising her voice, adding a uplifting "question mark" at the end of the statement, looking up at her students, and opening up her arms expansively as she issued the same verbal response (see Figure 4.1b), then her talk turn would constitute a redirection. In this second case, it is clear she intends her class to take up this student's comment as the next focus for discussion. As a point of fact, Mrs.

Miller's initial comment or question (posed to the class at the beginning of a session) would not be considered to be a redirection, since it serves to establish the initial focus of the class. Additionally, Mrs. Miller's bids that invite general comments, for example, "Bobby, what do you think about all of this?" are not considered to be redirections, since, on these occasions, Mrs. Miller is not providing a new locus upon which her students may focus their attention. Rather, her bid simply serves to perpetuate the current discussion.

Figure 4.1 *Mrs. Miller's Body Language that Typically Co-occurs with Verbal Responses.* (a) Body language typically accompanying a simple acknowledgement; (b) Body language suggestive of a redirection.

In the following section, the identification and characterization of redirections are described and exemplified.

4.3 The coding scheme

There are two primary categories of redirections (see Table 4.1). Redirections that attempt to shift the locus of the students' attention from one scientific phenomenon or question to another during a discussion are called "focus" redirections. Such redirections would include Mrs. Miller's comments and/or questions that: (1) introduce a new question for discussion, (2) refocus the students on an earlier discussion topic, (3) and/or broadcast a student's recent idea for consideration by the whole class. An example of an attempt to shift the students' focus would be Mrs. Miller inviting the students to move from discussing factors that affect the rate of evaporation (locus #1) to describing instances where they've witnessed water condensing on objects (locus #2). In contrast, redirections that attempt to shift the type of activity in which the students are engaged are called "activity" redirections. A move to shift the students from discussing the factors that affect evaporation (activity #1) to designing experiments to test how these factors affect evaporation (activity #2) would constitute an activity redirection.

Table 4.1 *Description and Exemplification of the Two Primary Categories of Redirection*

Change type	Redirection (RED) Description	Example/Elaboration
Focus	Bid to change the specific **FOCUS** of the students' discussion	MM invites her students to shift from discussing where the puddle went to elaborating the word "evaporation."
Activity	Bid to change in the **TYPE OF ACTIVITY** in which the students are engaged	MM invites students to shift from *discussing* where the puddle went to *designing* an experiment or *organizing cloud cards* into a matrix. Examples of different activities MM might have her students engage in: (1) *discussing* scientific phenomena, (2) *designing* and/or *carrying out* an experiment, (3) *listening* to MM lecture, and (4) *drawing and labeling* a representation of a demonstration.

Both focus and activity redirections may be accompanied by a change in the structural unit of the class's activity. For example, MM might issue a redirection to have students consider a new phenomenon (a focus redirection) AND change from whole class mode to working in small groups (a shift in structural unit). While such changes in structural unit are not considered redirections in and of themselves, they can provide additional evidence that a shift has occurred, suggesting a possible instance of a redirection.

Identifying an instance of an activity or focus redirection

In order to identify a segment of Mrs. Miller's talk as a redirection, Mrs. Miller's talk turns are submitted to a series of questions. These questions help to establish whether the talk turn: (a) is a redirection and, if so, (b) whether that redirection constitutes a focus or activity redirection. Figure 4.1 displays a flow chart that depicts this line of sequential questioning, which is elaborated in the paragraphs below.

First, Mrs. Miller's talk turn is assessed as to whether it involves the exploration or engagement with a scientific phenomenon of some kind. If it does not, as when Mrs. Miller is discussing housekeeping or disciplinary matters, it can be dismissed from further consideration. If, however, her talk does concern a scientific matter, then it evaluated as to whether it invites her students to shift from one scientific activity (e.g. discussion) to another (generating an experiment). If it does, the talk turn is coded as an "activity" redirection. This type of redirection often concurrently invites students to shift in their structural unit. For example, an activity redirection might consist of a bid to shift the students from discussing a phenomenon in whole class mode (activity #1) to designing and carrying out an experiment in small groups
(activity #2).

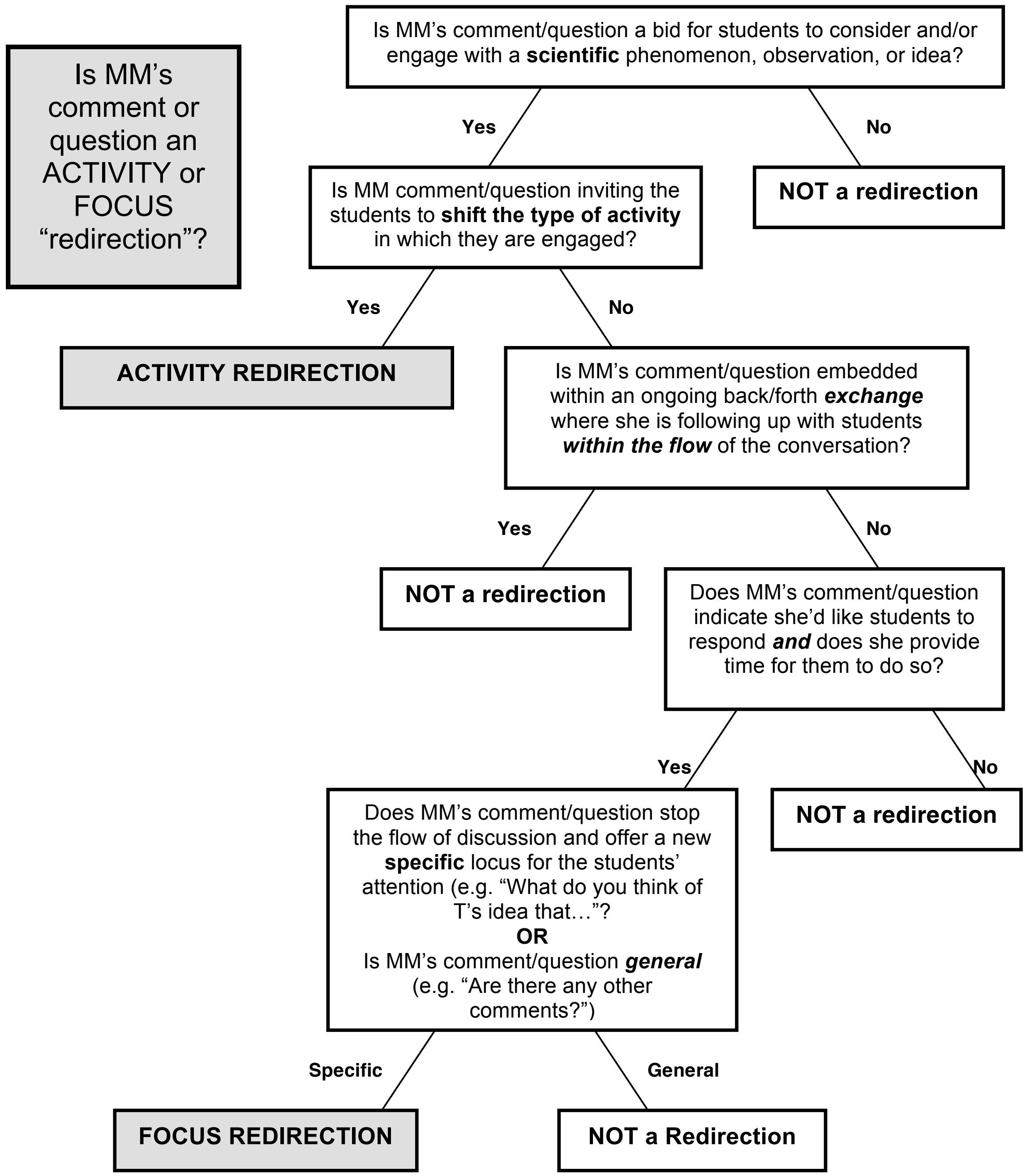

Figure 4.2 *Redirection Identification.*

If the talk turn is not identified as an activity redirection, it is then assessed as to whether it is embedded within an ongoing exchange between Mrs. Miller and one or more students. For example, if Mrs. Miller asks a student a follow up clarification question or if she makes a facilitation move between two students who are exchanging ideas, then her talk turn would be considered to be part of an ongoing exchange. This type of move would not constitute a redirection (see previous subsection).

If Mrs. Miller's comment is not considered to be part of an ongoing exchange, then it proceeds to the next question, "Does Mrs. Miller's comment or question indicate that she'd like her students to respond, and does she provide time for them to do so?" As mentioned previously, focus redirections must invite discussion and allow time and space for students to speak. If Mrs. Miller simply repeats a student's statement, without a clear invitation for the rest of her students to take up the idea, the talk turn would not be considered a redirection. Instead, it would be viewed as an acknowledgement of the student's contribution. Neither would a rhetorical question or statement be considered to be a redirection, since Mrs. Miller isn't providing her students with time to take up and discuss the idea.

Talk turns that are not a parrot of students' statements and do allow time and space for others to respond are subjected to one more line of questioning: (1) Is the talk turn general, in that it invites the students to make any comment to the ongoing conversation? Or, (2) does it provide a different locus for the students' attention, changing the direction of the conversation? If Mrs. Miller asks her students if they'd like to make any additional comments, then her bid does not attempt to shift the focus of the conversation. Rather, it serves as an attempt to perpetuate the current discussion and does not represent a redirection. If, however, she provides the students with a new scientific focus, the talk turn is identified as a focus redirection.

Further redirection coding: Activity redirections

Once a talk turn is established as either an activity or a focus redirection, it is then further coded according to the type of responsiveness reflected by the attempted shift. This portion of the analysis is not necessarily straightforward or simplistic. A bid to shift the students' attention taken out of context might appear to be thoughtful, however, closer examination of such a redirection might actually prove it to be minimally responsive. For example, if a class already spent time discussing a specific phenomenon, a prompt that appears to elaborate a student's explanation might constitute a simple recall question. Hence, the context in which the ongoing dialogue is embedded cannot be dismissed during analysis. Understanding the history and context of the discussion helps determine whether a statement or question represents a bid to: (a) shift the locus of the class's attention to something new, (b) return to a previous locus of attention, or (c) perpetuate the on-going discussion (the first two of which constitute a redirection, the last of which does not). Both the immediate dialogue and the larger discussion have to be considered when characterizing the level of responsiveness of a single redirection.

Activity redirections are further separated into two coding categories (see Figure 4.3). The first category includes those redirections for which there is evidence to support a claim that Mrs. Miller's redirection is grounded in, and therefore responsive to, her students' comments. This evidence may exist in the form of a direct connection between her redirection and student comments made during recent or previous class dialogue.

Talk turns that are founded in student comments are coded as "Activity redirection Connection 1" or "AC1" redirections.

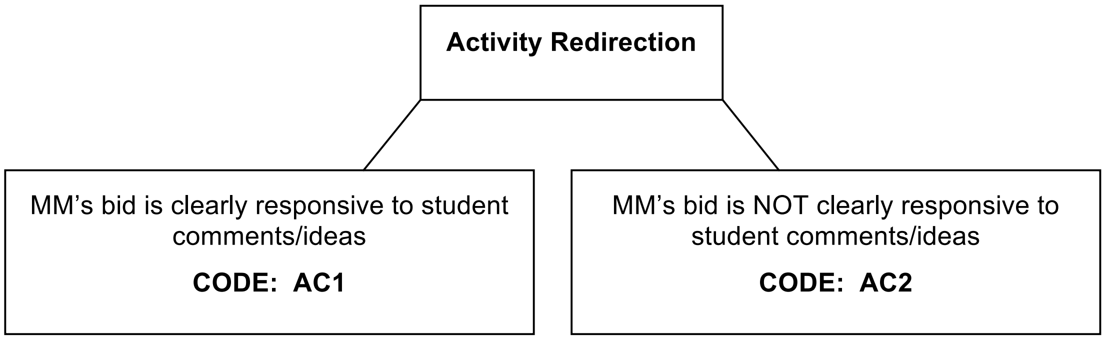

Figure 4.3 *Two Types of Activity Redirections*

Consider the two following examples of AC1 redirections. In the first classroom scenario, student N raises the idea to "test" another student's claim that liquids other than water are capable of evaporating. Mrs. Miller follows N's request with an invitation to her students to move from whole class discussion (activity #1) to designing investigations to explore the claim (activity #2). In the second scenario, a student (John) makes a connection between the emission of fog from dry ice and the evaporation of water vapor from liquid water. Other students elaborate this connection and further discussion ensues. The following day, Mrs. Miller revisits the topic and invites additional discussion (activity #1). After a while, she engages the students in actually observing the sublimation of dry ice (activity #2). In the former case, the bid to shift the students' activity directly followed the student comment, whereas the second bid was embedded within the following session. Both of these redirections, however, represented (successful) attempts to shift her students from whole class discussions to alternate activities grounded in students' comments.

The second category of activity redirections consists of those for which there is no clear evidence to indicate that Mrs. Miller's bid takes up her students' comments. Instead, the redirections seem to be grounded in Mrs. Miller's own agenda or goals for the session, predetermined or emergent. These types of talk turns are coded as "Activity redirection Connection 2" or "AC2" redirections. For example, midway through an animated discussion where students are considering various explanations for where a puddle of rainwater has gone (activity #1), Mrs. Miller invites the students to design and carry out experiments investigating factors that affect evaporation (activity #2). While shifting to the second activity certainly may advance the students in their understanding of evaporation, the shift doesn't seen to be consistent with the students' comments or discussion.

To further illustrate the difference between the two categories of activity redirections, examine the following two portions of transcript. The first piece concludes a discussion about the possible origin of water dripping off a bag of ice.

Transcript 4.3a [1.13.08:18]

Mrs. Miller: Did you hear that Jamie? Do you think the water that was dripping off that bag yesterday came from the inside of the bag, or from water vapor condensing on the outside of the bag? (pause) Or you're still not sure?

Jamie: Still not sure…

Mrs. Miller: Andre and Tyron?

Andre: We think the water vapor collects from the air.

Mrs. Miller: So it seems that most of us are in agreement now. We now feel strongly that it's the water vapor that's condensing on the outside of the bag because of the ice inside the bag is cooler temperature. … What could we do, or what could we set up that might help Jamie to better understand this? Because he's still not sure…whether that water dripped out of the bag… so what could we do? Turn in your groups, talk for a moment or two … What could we do that would help Jamie to understand this concept better?

In this class segment, Mrs. Miller invites her students to design hypothetical experiments to help Jamie better understand where the water dripping off the bag of ice originated. Her redirection *responds* to Jamie's expressed confusion in line 4, "Still not sure," by inviting her class to shift from discussing the ice bag phenomenon (activity #1) to designing appropriate experiments (activity #2). Such an activity shift exemplifies an activity redirection grounded in student comments. This shift is in contrast to that exhibited in the transcript segment shown below. It concludes a discussion concerning why water condenses on some surfaces and not others.

Transcript 4.3b [1.9.38:24]

Mrs. Miller: Chris?

Chris: I like how Tommy thinks it has to do with hot temperatures and Anthony thinks it has to do with cold temperatures. Maybe it has to do with the extremes of temperature. …

Mrs. Miller: Go ahead, Matthew?

Matthew: It has to do with both … because if you use metal… metal is usually cold for a long time, like when you take a car with dew on it, and there's not dew on the sidewalk… The water has to be hot to steam, the steam collected on it, it would have to do with both- It has to do with two temperatures.

Mrs. Miller: So temperature. So do we think we want to maybe try some type of experiment and see what we can come up with? [Class: Yeah.] So what is it that you want to try, that's what you need to write down right now, what are you thinking that will be able to help you? Now, write it down, let's see if we can come up with something.

At the onset of this segment, the students are grappling with the phenomenon of condensation. They are trying to account for why water will condense on some surfaces and not others. The students are building on each other's ideas (line 2, "I like how Tommy thinks…and Anthony thinks…") and actively working to develop an explanation for condensation that hinges on a possible interaction between two temperatures. It is at this point that Mrs. Miller stops the discussion (activity #1) and moves her students to developing "some type" [line 8] of experiment (activity #2). Unlike the previous activity redirection, however, this bid does not seem grounded in the student comments: the students are engaged in a lively and active conversation about the potential importance of two temperatures. It may be assumed that Mrs. Miller's redirection is an attempt to move the students forward in their understanding of condensation; however, there isn't evidence to suggest that it is directly connected to, and a result of, particular student comments. Thus, this redirection would be coded as an AC2 activity redirection.

As seen in the cases above, activity redirections are regularly accompanied by a shift in structural unit (i.e. both redirections attempted to move the students from whole class discussion to small groups designing experiments). Following such activity shifts, Mrs. Miller's students are often expected to share out thoughts about their experiences during the activity. Contrary to what might be expected, these moves from small groups to whole class discussion are *not* coded as activity redirections. First, these shifts are not necessarily shifting the students from one activity to another, for the students are describing aspects of the activity in which they'd just been engaged. Secondly, such shifts may be prompted by interactions that occurred *during* the small group (or individual) activity. For example, a student might share an idea with Mrs. Miller during the small group activity that prompts her to shift the activity of the entire class. Video data from these types of interactions are limited, however, and are not being considered for this project. As such, there isn't classroom evidence to support or refute a claim as to the level of responsiveness reflected in this type of shift. Only activity redirections that involve students shifting FROM whole class discussion TO a different activity are coded, not shifts in the opposite direction.

Further redirection coding: Focus redirections

Figure 4.4 displays a flow chart that traces the pathway by which focus redirection codes may be assigned. Unlike activity redirections, which are few in number and relatively easy to assess in terms of the presence (or absence) of responsiveness, focus redirections are far more numerous in the data set and more subtle in terms of the type and degree to which they reflect Mrs. Miller's responsiveness. Thus, coding them past the initial identifier of "focus redirection" is more complex than that for activity redirections. Table 4.2 describes and exemplifies the five different codes associated with focus redirections, all of which are explained briefly in the paragraphs below. Additionally, one of these codes, "FC1," is assigned an additional level of coding and will be further elaborated in section 4.4.

A focus redirection is first assessed as to whether there is evidence to show that it is clearly grounded in or directly connected to student comments that emerged within the last exchange sequence of talk. [By "last exchange sequence," I refer to the most recent set of interactions between Mrs. Miller and her student(s) that led up to the present redirection. The segment may consist of two talk turns (an initial prompt from Mrs. Miller and a single student's response) or may be considerably longer, if it contains a lengthy probing sequence with more than one student interjecting comments.] In other words, this first question determines whether Mrs. Miller is responding to her students' comments in the moment. If there is evidence to suggest that her redirection is connected to student comments from the last exchange sequence, then it is coded as a "Focus redirection Connection 1" or "FC1" and, subsequently, further descriptively coded according to the nature of its connection/relevance to student comments (see section 4.4 and Tables 4.3 – 4.6 for further elaboration of these codes).

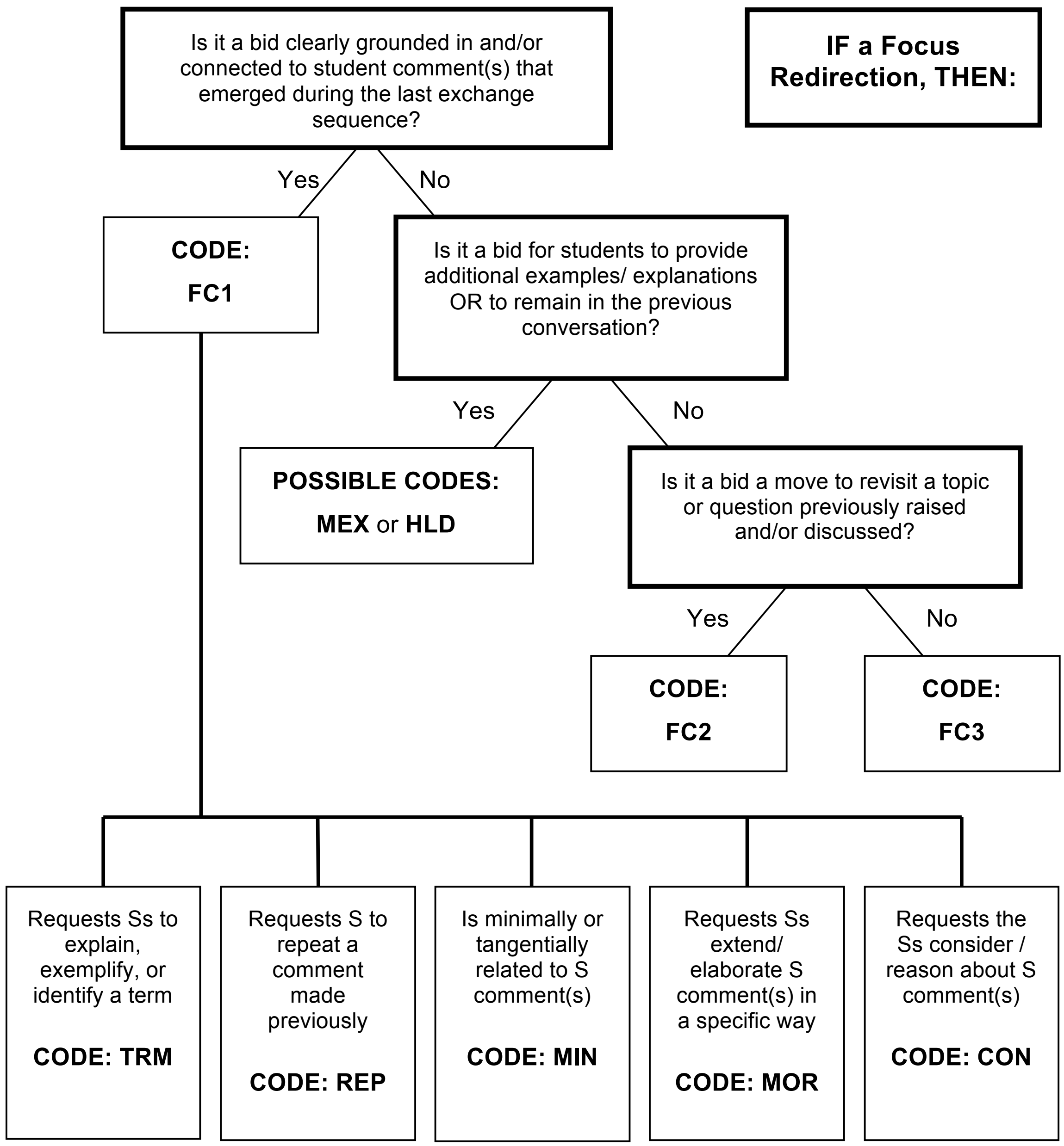

Figure 4.4 *Focus Redirection Flow Chart and Codes*

Table 4.2 *Additional Focus Redirection Codes: Connection to Student Comments.*

Code	Description	Example
FC1	**Responsive:** RED is clearly grounded in and/or connected to student comment/idea(s) raised during the last exchange sequence (although it may not be the very last comment, however).	MM asks students what they think about student L's comment, "Clouds need a cold environment." [1.2.30:49]
FC2	**Delayed responsive:** RED is *disconnected* from student comments during the last exchange sequence; however, it invites the students to *revisit, discuss, and/or elaborate* phenomena considered, ideas contributed, or questions previously raised.	MM invites the students to revisit a phenomenon discussed during the previous day (i.e. water dripping off a bag of ice) and encourages student C to share his thoughts on the phenomenon. [2.14.03:27]
FC3	**Not responsive:** MM's bid to shift to a new discussion topic does NOT appear connected to student comments/work. [NOTE: These shifts may connect to the overall theme of the discussion; however, they do not appear to be grounded in, or responsive to, the students comments themselves.]	After discussing occasions where water vapor turns back into liquid water, MM asks the students whether there are gases other than water vapor "that are in the air all the time." [1.8.SEC.36:23]
FMEX	MM specifically requests that her students provide additional examples, ideas, comments and/or explanations for the topic under discussion.	MM stops a discussion concerning one modification proposed for an experimental model to ask the students if they have any additional suggestions for modifications [1.11.32:47]
FHLD	MM requests that her students hold off providing additional examples or explanations in order to allow for further discussion on the current topic.	MM asks students to hold off providing additional proposals for which clouds causes lightning, in order for two students to further elaborate opposing points-of-view. [1.3.06:17]

Note. MM = Mrs. Miller.

If the redirection does not exhibit a connection with recent student comments and, thus, is not coded as an instance of FC1, it is evaluated as to whether the redirection represents a bid for students to provide more examples or explanations ("MEX"), or if it is a bid for students to hold off presenting more examples or explanations in order to allow further discussion on a topic ("HLD") (see Table 4.3). Consider, for example, the following focus redirection. After Mrs. Miller's students spend time elaborating one specific explanation for where a puddle of rainwater has gone (focus #1), Mrs. Miller invites her students to propose additional explanations for where the puddle might have gone (focus #2). This is an instance of the MEX code, as Mrs. Miller is requesting that her students provide additional explanations for a specific scientific phenomenon. In another segment of the class discussion, however, Mrs. Miller stops a student as he proposes a new topic of conversation, requests her students collectively "hold off" providing more explanations, and requests that they further discuss the most recent topic under consideration. This type of redirection represents an instance of the HLD code.

If the focus redirection cannot be coded as an instance of FC1, and it doesn't constitute the special instances of MEX or HLD, then it is examined to see if it represents a bid to revisit a scientific question or phenomenon previously raised and/or discussed. If the redirection fits into this category, then it is coded as an instance of a "Focus redirection Connection 2 or "FC2." For example, after the class engages in an extended conversation about water evaporation from puddles and cups (focus #1), Mrs. Miller stops the conversation and invites her students to reconsider an experimental set up described earlier by a student (T) (focus #2). While this redirection is clearly not grounded in comments that emerged during the last sequence of talk, it can be viewed as responding to student comments that were made at an earlier time. Such FC2 redirections can be considered as reflecting a level of "delayed" responsiveness, since they are returning to a previous topic after some time delay.

Any redirections that do not exhibit characteristics of any of the previous categories, and, therefore, constitute attempts to shift the students' attention to a new question or phenomenon, are coded as "Focus redirection Connection 3" or "FC3" redirections.

4.4 Elaborating Focus redirection Connection 1 (FC1) codes

FC1 codes, as described cursorily in the previous section, are assigned to redirections that indicate that Mrs. Miller is responding to her students' comments in the moment. Preliminary analyses of the classroom data suggested that Mrs. Miller took up her students' comments in different ways. For example, there were occasions where Mrs. Miller seemed to take up the essence of the students' comments and put it on display for consideration by the entire class. There were other instances, however, where Mrs. Miller seemed to take up the students' comments on a very superficial level, using their comments as stepping-stones to move ahead to another topic or concept. While it is arguable that Mrs. Miller is responding to her students' comments in both of these types of situations, in the former she allows her students to direct and guide the process of inquiry, whereas she shapes the pathway and trajectory of discussion in the latter. These two types of FC1 redirections seemed to reflect different types and degrees of responsiveness and, as such, warranted different codes. Ultimately, five FC1 codes were distinguished, each of which are defined and exemplified in the subsections below.

FC1 code: Minimal (MIN)

There are many instances of classroom talk where Mrs. Miller's bid to shift the attention of the class seemed to be *minimally responsive* (Pierson, 2008) to student comments made during the last exchange sequence of talk. In each case, there was evidence to indicate that Mrs. Miller's question or statement was grounded in the student's comment; however, it was sufficient only to support a limited connection to the student idea. Consider the segment of transcript shown below, which was taken from a whole class discussion concerning the factors that affect evaporation.

Transcript 4.4a [3.2.SEC.06:08]

Emma: To record how long the puddle was in the sun.

Mrs. Miller: So we didn't even say that it was a sunny day or shady day, so are we writing that down, too?

Emma: Yeah.

Mrs. Miller: So we're going to record what? What are we going to record?

Emma: The weather.

Mrs. Miller: The weather, okay, so you want to record the weather, you seem to think that's important, so record the weather. (turns to face the class) And by weather, we mean what? Sunny, cloudy or what? … Now even if it's sunny or cloudy, where could that puddle be? I mean it might be sunny here, but the puddle's over here.

Donald: The location.

In the example above, Mrs. Miller seemed to use Emma's comment in line 5, "The weather," as a stepping stone to move the students from considering how weather might affect a puddle of rainwater (focus #1) to discussing the how location might affect the puddle (focus #2). Redirections such as this do not so much take up the student's "idea;" rather, such instances seem to reflect Mrs. Miller using a student comment as a link to the next topic of discussion. FC1 redirections such as these are assigned the "minimal" code (MIN).

Table 4.3 *Descriptions and Classroom Examples of Different FC1 MIN Redirections*

	Descriptions and examples	
Focus Connection 1 "Minimal" (FC1 MIN)	**Minimal connection:** MM asks a new question that is only tangentially, superficially, or minimally related to the previous topic of discussion.	MM: E? E: Measure. MM: Measure it…(to class) ***Are we going to trust our memories?*** [3.2.SEC.04:11]
	Minimal extension: MM asks question that "extends" the previous student's comment(s), but it is clear that it is MM's thinking (and agenda) is on display, not the student's.	MM: Because M's doing a really good job with the beginning. Who wants to finish? ***This is only half of it, what's the rest of this?*** [1.12.57:59]
	Evaluative: MM repeats and/or asks a related question to that which she previously posed to a single student or the whole class, seemingly because student(s) didn't answer in the manner of which she'd hoped.	MM: (follow up to a student) How high? (Student answers) Twelve feet….So, that low? (To whole class) ***What's the highest you've seen fog?*** [1.2.09:11] MM: (follow up to a student) So the glass is cooler than what? K: The water. MM: (to class) ***Glass is cooler than surrounding what?*** [1.9.36:02]
	Stepping-stone: MM repeats student comment and asks a question that clearly moves the students FROM the previous comment TO the next and related topic. These REDs often occur in series (e.g. several in a row).	MM: (to class, in response to a student's comment that they could use 8 ounces of liquid) ***What is really the language of science when it comes to using a mathematical system? Do we use standard measurement, or do we use something else?*** R: In science, we use the metric system. MM: (to class) …So, the metric system. ***What might we say then, for a volume of water?*** Y: We call it a liter. MM: So that'd be for a big bottle…(to class) ***Let's say I wanted an amount that was like this*** (indicates a small water bottle) ***amount.*** [2.4.04:52]

Note. MM = Mrs. Miller.

FC1 MIN redirections can take on various forms. Some redirections use previous comments as a stepping-stone for the next topic or concept, where Mrs. Miller shifts her students from one topic area to another in a series of one or more steps. Others seem to represent an evaluation type move on the part of Mrs. Miller, as when she asks a question only to repeat the question following a student's incorrect response. Collectively, they all represent redirections that are only minimally connected to student comments. Table 4.3 provides classroom examples of several different kinds of MIN redirections. These examples are provided in order to display the range of possible redirections that are collectively coded as "FC1 MIN." While future work might explore possible implications of the specific MIN varieties, at present all are collectively considered as instances of the same code.

FC1 codes: Elaboration (MOR)

While some of Mrs. Miller's bids seemed to take up the students' ideas in a superficial way, there were many turns of talk where she issued a redirection that was highly responsive to students' comments (e.g. the teacher takes up the essence of the student's idea, Pierson, 2008). In these instances, Mrs. Miller takes up her students' ideas and presents them as the focus for further discussion. For some, the manner in which she took up their ideas was such that she invited her students to collectively take their observations or explanations a step further. This allowed her class to explore, extend, and/or generate a deeper understanding of scientific phenomena under consideration. These FC1 redirections were assigned the "elaboration" code (MOR).

Table 4.4 *Descriptions and classroom examples of different FC1 MOR redirections*

	Description	Example
Focus Connection 1 "Elaboration" (FC1 MOR)	**Mechanism:** MM asks students to propose or elaborate a mechanism that underlies a scientific explanation.	MM: If clouds are water [a statement upon which the students, as a group, just agreed], ***how does that water get to the clouds?*** [2.3.02:48]
	Evidence: MM asks the students to provide evidence to support their claims.	MM: Why do you think that? ***What evidence do you have to convince [those that do not agree with your explanation]?*** [3.6.34:57]
	Justification: MM invites the students to justify and/or provide reasoning to further explain themselves.	MM: (Summarizes a student generated procedure for the whole class)…And then we're going to put it in a bag…***Why are we putting it in the bag?*** [1.13.30:19] MM: So, I'm hearing it's kind of like a puddle, but you could observe it more***. What is it that makes it more observable when it's in a container?*** [3.3.32:21]
	Making connections: MM invites the students to draw connections between a particular student's comment and: (1) another student's comment, (2) the initial question or phenomenon posed for consideration, or (3) other experiences they've had.	MM: So, I want to go to what J said. You gave an example. N gave an example of the same situation, but then he turns the fan on and the steam goes away. S described another example. S described one. ***What do all of those examples have in common and what is it that you're trying to explain by giving those examples***? [3.14.19:15] MM: ***How does that*** [student's comment] ***relate back to the puddles of rainwater***? [1.1.10:30] MM: ***Can you connect what H says to real life? Windy day, no wind day***? [1.7.SEC.00:49]
	Compare and contrast: MM invites the students to weigh the advantages and disadvantages of different students proposals or explanations.	MM: So we have E and N thinking we could just make a puddle and observe it. ***Is there an advantage over making a puddle? Is it better or is using a cup better?*** [3.3.15:46]
	Extension: MM asks the students a question that extends a comment *initially raised by a student*. Hence, MM is taking up a student's comment and inviting others to elaborate it.	MM: (in response a student raising the idea that if you can't see 3 or 4 atoms, you can't see 1) ***Are all atoms the same size?*** [1.12.31:58] E: (replying to an MM question) You can look on the back of the bottles and … it has water in them. It says what's in it besides water. MM: (to class) ***What if it just says something like…100% orange juice?*** [3.9.37:21]

Note. MM = Mrs. Miller.

FC1 MOR redirections, like those belonging to the category of FC1 MIN, come in several varieties. All MOR instances serve to invite the student(s) to extend and/or elaborate comments made during recent discussion *in a specific way*. Such bids, if successful, serve to shape subsequent discussion by providing a possible structure upon which to build. For example, following a lengthy discussion where Mrs. Miller's students generate a consensus that it is "puffy clouds with dark gray bottoms" that produce lightning (focus #1), Mrs. Miller asks them why those clouds produce lightning (focus #2). This both extends the students' comments and serves to shape the subsequent discussion, by inviting her students to talk about the clouds in a specific way (i.e. provide an account for why/how they produce lightning).

Similar to the FC1 MIN redirections, FC1 MOR redirections come in several different forms. Collectively, FC1 MOR redirections all serve to elaborate student comments. FC1 MOR bids often resemble probe-type questions that might be asked to follow up with a single student. What distinguishes FC1 MOR redirections from simple probes, however, is that the redirections are offered to either the *whole class* OR a student other than the one who made the original comment(s). Table 4.4 displays different examples of FC1 MOR redirections.

Interestingly, many of the redirections that are coded as FC1 MOR are phrased as "yes/no" questions. These questions, while simplistic on the surface, do not necessarily carry the implication that Mrs. Miller desires her students to respond with a one-word answer. Rather, these openings represent a launching pad for further discussion, as evident from the students' often lengthy and highly reasoned responses to such "yes/no" questions. For example, after a student (H) makes the claim that water exposed to a fan would evaporate more slowly than still water because moving water is not hit directly by the sun's rays, Mrs. Miller turns to the class and says, "Can you connect what H says to real life? Windy day, no wind day?" This FC1 MOR redirection is technically a "yes/no" question; a student could answer, "Yes, I can connect it." However, it can be inferred from the phrasing of the question that Mrs. Miller is requesting that her students move beyond a simple affirmative (or negative) answer. Her question seems to imply that she is interested in *how* such a connection might be made. This underlying assumption is supported by student C's response shortly thereafter, when he states, "I disagree with H, because rivers…They're moving waters and…they evaporate more than lakes." Hence, while FC1 MOR redirections may look simplistic on the surface, requiring little reasoning or elaboration, in actuality they are demanding and empowering of her students, in terms of allowing them to further their pursuit of scientific inquiry and understanding.

FC1 codes: Consideration (CON)

Another type of redirection that reflects a high level of responsiveness (e.g. the teacher takes up the essence of the student's idea, Pierson, 2008) is that belonging to the code "consideration" or "FC1 CON." In talk turns belonging to this category, Mrs. Miller's bid to redirect her students is clearly responsive in that she takes up a student's comment (or a collection of students' comments) in part or in entirety and invites the students to consider and reason about the comment on its own merits. For example, during a discussion about types of clouds student (L) proposes that, "All clouds need a cold environment." Mrs. Miller then turns to her class and asks, "What do you think of

L's comment that all clouds need a cold environment?" In this instance, MM places the burden of how L's comment is considered and where to go with the discussion next completely on the shoulders of the students. She makes a bid to move the students FROM describing different types of clouds (focus #1) TO considering L's statement (focus #2). Mrs. Miller's FC1 CON redirections serve as invitations for students to consider, reason about, and/or discuss each other's comments without her necessarily imposing structure to the subsequent conversation. Hence, the power of this redirection, if ultimately successful, lies with the students.

Table 4.5 *Descriptions and Classroom Examples of FC1 CON Redirections*

	Description	Example
Focus Connection 1 "Consider" (FC1 CON)	**Individual Consideration:** MM asks the students "what they think" of another student's comment, whether another student's comment "makes sense," if they have a question or comment about a particular student's idea, or if they agree with a particular student's idea.	MM: So [T is] saying only shallow water evaporates. ***What do you think about that, B?*** [1.1.17:59] MM: ***Does that make sense? [J's analogy of] walking into a big ice bog?*** [3.13.07:14] MM: ***Do we agree to that? Yes? Indicate somehow that you agree with D that there would be heat.*** [2.1.43:20]
	Collective Consideration MM asks the students to consider their collective comments and decide whether they've (collectively) answered a question.	MM: ***Have we answered the question, "What causes rain?"*** [1.10.03:34]
	Interpretation: MM invites the students to explain or interpret another student's comment.	MM: J made a good comment…***He said…clouds look different at different heights. So, what does that mean?*** [1.2.22:08]
	Inquiry: MM rebroadcast's a student question for the rest of the class to discuss.	MM: ***Why did I use warm water?*** That…is a very legitimate question. ***So, does anyone want to answer, why?*** [1.11.32] MM: ***A wants to know what will happen to the condensation on the sides of the container, not the plastic wrap.*** [1.12.27:19]

Note. MM = Mrs. Miller.

As with the two FC1 categories of codes previously described, there are several examples of FC1 CON redirections. Table 4.5 describes and provides examples of these. Consistent with many FC1 MOR, FC1 CON redirections can take the form of “yes/no” questions. For example, Mrs. Miller may turn to her students and ask, “Do you agree with that?” following a student’s explanation. Questions like this, while superficially simplistic, do carry an implicit request that students consider the previous student’s comment when they respond and supply reasoning behind their response.

Rare FC1 codes: Term (TRM) and Repeat (REP)

There are two additional types of redirections that reflect Mrs. Miller’s in-the-moment responsiveness to her students’ comments. These two codes are: “term”(TRM) and “repeat” (REP). Instances of these redirections were found in the data set much less frequently that those of the three codes discussed in the previous three subsections. However, these types of redirections were categorically different than the other FC1 redirections, and examples of them were found across implementations. Hence, such redirections warranted distinct codes. The designation FC1 TRM was assigned to instances where Mrs. Miller requested her students to define, explain, or further elaborate a scientific vocabulary term or phrase that had arisen in recent dialogue. It was also assigned to instances where Mrs. Miller asked her students to provide or identify a vocabulary term relevant to the ongoing discussion (see Table 4.6).

The FC1 REP code was assigned to redirections where, in response to a student’s comment, Mrs. Miller invites a different student to repeat a specific comment or question he or she made earlier. Consider the excerpt of transcript presented below.

Transcript 4.4b [1.3.30:37]

Britta: I- was playing cards with my dad one night. And it was really- we have a screen door on the right- leading to the backyard? And we were sitting playing cards? And I looked to the right, and- … And the lightning came down really close to the ground by the screen door? And it just didn't come back. Like it didn't do it again. …

Mrs. Miller: Do you think that has something to do with what Brandon said? Earlier? (Holds hand out horizontally) About- (turns to Brandon) Repeat what you said about the fact-

Brandon: The cloud usually moves during it's- when it's coming? (Holds out hand horizontally) Because it would go- (demonstrates lightning shooting out from a cloud). Woooo- dush- dush- dush.

In this example, Mrs. Miller seems to recognize Britta's observations of lightning as consistent with an explanation of lightning previously given by Brandon (e.g. "Do you think that has something to do with what Brandon said? [line 5]). As such, she responds to Britta's comments by inviting Brandon *repeat* his earlier explanation (e.g. "Repeat what you said about the fact-" [line 6]). Brandon then shares his explanation of lightning once again, via hand gestures (lines 7-8).

There are clearly similarities between instances of REP and those of FC2, since both redirections shift the students' attention to topics already discussed. The distinguishing feature of FC1 REP redirections, however, is that the invitation for a student to repeat an earlier comment can be directly linked to a student comment that emerged during the last exchange sequence. Mrs. Miller is, thus, responding to her student in the moment by inviting another student to repeat an earlier comment that brings something to bear on the current student's comment. Table 4.6 provides additional descriptions and classroom examples of the FC1 TRM and REP codes.

Table 4.6 *Descriptions and Classroom Examples of FC1 TRM and FC1 REP Redirections*

Code	Description	Example
FC1 TRM	RED invites students to explain, exemplify, or *identify* a specific ***term*** and/or phrase that has emerged through discussion. While the term may have been mentioned several times during the session's discussion, it must have been raised at some point during the most recent exchange.	MM asks students to further explain what they mean by the term "evaporated." [2.1.04:29]
FC1 REP	RED invites a student to ***repeat*** a previously made comment or describe a previously carried out activity, since it brings something to bear on the current topic/question being discussed. [NOTE: This does not include MM's immediate requests for a student to repeat what he or she JUST said, as this would constitute a simple or follow-up question.]	MM asks student (Adrienne) to repeat her earlier comment, since it seems to be in direct contrast to a comment just made by another student (Allen) [3.5.49:48]

Note. MM = Mrs. Miller.

4.5 Establishing inter-rater reliability

Internal reliability of the redirection coding scheme was sought via extensive cyclical coding. Constant comparison (Strauss, 1987) between successive versions of the scheme and the coded classroom data was conducted until additional comparisons yielded few, if any, coding changes. The stabilized scheme presented here was administered to the entire data corpus in a final round of coding to examine internal consistency of the redirection codes. In this final analysis, most codes were modified in less than 5% of the instances in which they were encountered. This consistency was believed sufficient to establish a stable scheme.

Late in the development of this redirection scheme, two individuals were trained using the current version of the scheme and asked to code several non-overlapping segments of classroom data. These segments collectively represented approximately 9%

of the data corpus. For several reasons, the segments were purposively selected, rather than selected at random. First, segments of whole class discussion greater than ten minutes were sought, in order to provide coders with enough contiguous discourse from which to code several redirections in one segment and have enough contextual information to determine the type of responsiveness represented in instances of the FC1 code. Secondly, segments were selected from all three implementations, in order to determine if the coding scheme could reliably be applied across the entire set of data. Lastly, the chosen segments provided the coders with instances of a range of different codes (FC1, FC2, FC3, etc). [NOTE: As this round of reliability coding was viewed as still preliminary, only percentages of agreement were calculated. Cohen's kappa statistics, with their associated corrections made for chance agreement among coders, were calculated *in addition* to levels of agreement during the final round of coding.]

When the two external coders' findings were compared with my own coded data, agreement percentages varied. With respect to the identifying of instances of redirections within Mrs. Miller's discourse, there was 92.1% agreement. Of the redirections mutually identified, there was over 98% agreement when identifying whether the redirection was an instance of an activity or a focus redirection. These high levels of agreement suggested that the initial questioning sequence (Figure 4.2) to identify and code redirections was comprehensive and could be applied reliably. Coding redirections beyond the primary categorization of "focus" or "activity," however, proved to be more challenging for the coders, yielding only 65.6% agreement. This lower level of agreement can be explained, in part, by the fact that coding redirections beyond their initial category requires an examination of context. In order to distinguish between an instance of an FC2 redirection and that of an FC3, for example, a coder must be able to determine whether the redirection revisits a previously discussed topic or if it represents a move to an entirely new focus area. An individual who is not familiar with the entire data set may not have enough background to know which topics had been discussed during previous instructional sessions. Hence, assigning FC2 or FC3 codes effectively would be difficult, if not impossible, for external coders. By eliminating instances of the FC2 and FC3 codes, the agreement among coders improved to 75.0%. While this level of agreement was certainly better, it was still less than that which I sought.

As a result of the lower levels of inter-rater agreement, the coding scheme and its associated description/question sequence were modified one final time to reflect a more systematic and efficient method of assigning codes. In particular, the means by which to distinguish the different FC1 codes were better characterized and exemplified. The description and flow chart were subsequently provided to two external coders, along with an additional set of class data segments to code. One of the two external coders had been previously trained with a prior version of the coding scheme, while the second coder had no prior experience with the construct or coding scheme. The segments chosen for this round of coding were specifically selected to present coders with a good cross-section of the data corpus and included instances of both focus and activity codes, as well as some of the codes (e.g. REP, AC1, AC2) less frequently encountered. The set of seven transcript segments totaled approximately thirty-five minutes of classroom time (roughly two percent of the whole class discussion data). This time, unlike the previous round of coding, both external coders were given the *same* set of transcript segments to code.

Levels of agreement, as well as Cohen's kappa values, were calculated for the coded data.

Prior to discussion, the coding levels of agreement across the three coders (two external coders and myself) were as follows: With respect to the identifying of instances of redirections within Mrs. Miller's discourse, the three coders agreed for 93.0% of the talk turns coded. Of the redirections mutually identified, there was 86% agreement in identifying whether the redirection was an instance of an activity or a focus redirection. With respect to coding beyond the category of "activity" or "focus" redirection, however, the coders agreed only 47% of the time. When the coded classroom data were corrected for chance agreement among coders, the Cohen's kappa calculation resulted in a value of 0.50. While this value can be considered within a range of fair to good reliability (Potter & Levine-Donnerstein, 1999), it is less than that which is considered to represent "excellent" reliability (i.e. 0.75).

In their paper on rethinking validity and reliability, Potter and Levine-Donnerstein (1999) contended that for analysis of content, the Cohen correction value can be viewed as overly conservative, especially when multiple coders code data with multiple nominal categories. As such, Potter and Levine-Donnerstein proposed an alternate means of calculating a chance agreement correction value. Substituting this adjusted value into Cohen's formula, the resultant kappa statistic for the coded segments of Mrs. Miller's classroom activity is 0.68. This value, while considerably higher than the previous statistic of 0.50, is still below the desirable value of 0.75.

Once the segments of transcripts had been independently coded, coders engaged in dialogue about the coded data. These conversations predominantly concerned the greater context surrounding specific exchanges between Mrs. Miller and her students. After discussion, coders' agreement for focus vs. activity redirections improved from 86% to 91%. Discussion also led from the original 47% to 85% agreement among the coders when assigning individual codes beyond the "focus" and "activity" designations. Cohen's kappa statistic values on the "revised" data improved to 0.72 (Cohen's original correction) and 0.82 (Potter & Levine-Donnerstein's correction).

The results from this round of reliability coding seem to indicate three things. First, the findings seem to reaffirm that the coding scheme is reliable with respect to identifying a particular teacher talk turn as an instance of a redirection (or absence thereof). Second, these findings seem to reaffirm that the coding scheme is reliable with respect to assigning a particular redirection as an instance of either a "focus" or "activity" redirection. Third, although Cohen's kappa values suggest that the coding scheme is reasonably reliable, the findings show that assigning codes *beyond* the "focus" or "activity" designation is challenging for coders (especially with respect to coding the type of focus redirections). I ask, then, the question: *why?* Why is it so difficult for coders to independently agree on what type of a focus redirection a specific talk turn represents? The answer, I contend, lies in *context*.

When independent coders are given classroom data to code, they are given segments of transcript and the corresponding video recordings. They are *not* given the entire set of classroom data that occurred prior to transcript segments, however. Asking coders to familiarize themselves with the entire data corpus would be impractical. However, due to the nature of the flexible and open-ended curriculum, ideas and comments made earlier during discussion (sometimes in a previous class session) often inform ideas and comments at later points in the discussion. Without a comprehensive knowledge and understanding of what came *before* a student/teacher exchange, it would be difficult for anyone to understand exactly to what the teacher or student may be responding. Thus, for a coder unfamiliar with the historical context for a particular segment of transcript, it would necessarily be challenging to assign appropriate codes as to the nature of a teacher's responsiveness. Consider the redirection in Transcript 4.5a shown below. The class segment was taken from a session during the second implementation of the water module.

Transcript 4.5a [2.13.46:37 – redirection is in ***bold itaics***]

Mrs. Miller: Just feel the outside of the bag, feel the bag, just feel it, just take it like that (rubbing fingers). He's got water on his hands, not just coldness, his fingers didn't just get cold, they got wet, right? Do it again?

Martin: They're all wet.

Mrs. Miller: Actually, look, water droplets on his hand off of this bag. So my question to you is: ***Where does that water come from that's on the outside of the bag?*** (to Martin, who has raised his hand) Have a seat and tell us. (to class) So Martin has got a theory about this, he's been taking notes. So Martin, share those theories with us…

Mrs. Miller's redirection, "Where does that water come from that's on the *outside* of the bag?" in lines 7-8, is clearly grounded in Martin's observation that his hands are all wet. However, it is less clear *how* it is related to that comment. If the class had already discussed condensation extensively, and the students were already familiar with the process of water vapor forming liquid water on a cold object, then this would be an example of a FC1 MIN redirection (*minimal* connection to a student's comment). If, on the other hand, the students had not discussed this concept previously, then her redirection could be understood to be an elaboration of Martin's observation. Thus, the redirection would be coded as FC1 MOR. [NOTE: In actuality, the class had not previously talked about condensation.] This segment of transcript illustrates the challenge of assigning codes when the historical context of the class is unknown.

While external coders may attempt to apply the coding scheme accurately on their own, it is only through discussion with an individual familiar with the data corpus (in this case, me) that they can fully come to understand relevant context. It is therefore not surprising that the percent agreement among coders improved so dramatically after discussion (e.g. an improvement from 47% to 85% when assigning specific “focus” redirection codes). For the purposes of this study, the calculated agreement levels of 85% or greater following discussion, in conjunction with the corrected kappa value of 0.82, were considered to be acceptable.

CHAPTER 5: ANALYSIS OF PRACTICE: MRS. MILLER's REDIRECTIONS

A focus on Mrs. Miller's redirections enabled me to characterize a dimension of Mrs. Miller's practice that spoke directly to her responsiveness to students. The construct afforded a means to examine her practice during short intervals of time (e.g. single sessions) and allowed for claims to be made about her change in practice over time (e.g. across three implementations of the water module). The following chapter presents the analysis of Mrs. Miller's practice using the redirection construct, beginning with a brief overview of the three implementations (section 5.1). In sections 5.2 and 5.3, I discuss Mrs. Miller's activity redirections and focus redirections across the three implementations. Section 5.4 then extends the use of the construct as a means to describe change by exploring how redirections can serve to extend the "life" of a student's idea. The final section (5.5) briefly summarizes the results and highlights a few implications of these analyses.

5.1 Overview of the module implementations

The water cycle module, as described in section 3.3, was designed to provide students with time and space to share their ideas and present teachers with the room and flexibility to pursue these ideas *as they emerge* through discussion and investigation. Each of Mrs. Miller's three implementations of the water cycle module began with a question[12]:

> Suppose that one night it rains. When you arrive at school, you notice that there are puddles of rainwater in the parking lot. When you go home, you notice that the puddles are gone. What happened to the rainwater?

The discussions that followed this "launching" question ultimately led to dramatically different journeys, touching on a variety of scientific phenomena, questions, and explanations. For example, the first implementation included animated student attempts to answer such questions as, "Which clouds cause lightning?" and "What causes rain?" Implementation 2 included conversations concerning how clouds might get around mountains and whether a substance could get too hot to evaporate. The third implementation of the water cycle involved an examination of a student's claim that "water evaporates in layers" and a lengthy exploration of the question, "Can liquids other than water evaporate?" While the route traveled (and list of specific topics/questions covered) was different across implementations, each one included time for considerable student discussion, investigation, and reflection. Additionally, all three implementations incorporated discussions of broad water cycle concepts, such as evaporation and condensation, as well as the factors that affect these processes.

Table 5.1 *Total Time and % Spent in Different Activity Structures Across Implementations*

Implementation	# of class days	Total class time (h)	% in whole class discussion	% in small student groups	% on individual work	% in other modes[a]	Shifts between activity structures
1	14	13.33	66.4%	29.5%	3.4%	0.7%	54
2	14	15.00	60.6%	33.2%	6.2%	0.0%	59
3	15	15.25	69.6%	19.3%	10.4%	0.7%	63

[a]Other activity modes (which occurred very rarely) included teacher lecture and student reporting for a classroom visitor.

Table 5.1 displays basic statistics for each of the three implementations of the water cycle module. Of the total time spent in module, students spent between 60 and 70% of their time in whole class discussion during all three implementations. By "whole class discussion," I specifically mean segments of class where the students are actively involved in dialogic exchanges with each other and Mrs. Miller *as one collective class unit*. The rest of the time was spent predominantly in small groups (19-33% of class time) and individual work (3-10% of class time). Less than 1% of the total amount of module time was devoted to listening to the teacher lecture. While this might seem unusual, since the standard for many teachers is a more didactic approach to science instruction, this low percentage is not unexpected considering that the format of the water cycle module is open, flexible, and designed to promote the sharing and discussion of student ideas.

The results displayed in Table 5.1 show the existence of several interesting differences among the implementations. First, the duration of the first implementation was considerably shorter than that of implementations 2 and 3 (thirteen hours twenty minutes versus fifteen hours plus). Mrs. Miller's first attempt at implementing such a flexible and emergent "curriculum" was wrought with hesitation, uncertainty, and stress, as evident by her comments during class, debriefing interviews, and professional development sessions. On several occasions, she expressed anxiety about "not knowing" what was to happen next and concern as to how to best prepare for class. Consequently, she tended to be eager and ready to terminate class, both at the end of the individual sessions and at the close of the module implementation. The second and third implementations seemed to be comparatively easier for Mrs. Miller. With experience, she appeared to become more accustomed to the open format of the module. She expressed greater willingness to alter plans during class, comfort with the "uncertainty" of what lay ahead, and confidence that she could respond to her students appropriately.

Thus, she tended to be more willing to let class sessions move at their own pace and allow extra time when needed. Mrs. Miller even opted to add on an “additional” class session at the end of the third implementation, in order to make up a day missed earlier due to a scheduling conflict.

Secondly, while the percentage of time spent in different structural units changed across implementations, Mrs. Miller had her students engage in whole class discussion, small group work, and individual work to some extent during all three implementations. Furthermore, Mrs. Miller consistently encouraged her students to shift between modes (e.g. whole class to small group) an average of three to four times per class session. The instructional strategy of having students move between structural units is consistent with Mrs. Miller’s desire to have all students participate in, and be accountable for, their own learning, a consideration she raised in several debriefing interviews.

A third point of discussion concerns the increase in the percentage of time devoted to small group work during the second implementation. This increase was due in great part to an extended stretch of student experimentation that took place during this implementation. Mrs. Miller engaged her students in at least one round of designing and conducting investigations in all three implementations; however, the students in implementation two were given the time and space to carry out investigations that were considerably more involved in terms of time and effort. As part of this process, the students spent a fair amount of time designing and conducting their experiments in groups of three. They also discussed their experimental set-ups with their classmates and provided feedback to one another. Ultimately, this round of experimentation extended for the greater portion of seven class sessions, most of which was spent in small group work. As a result, there was less class time spent in whole class discussion (61%) and more time spent in small groups (33%) as compared to the other two implementations.

Finally, it is worth highlighting the steady increase in the amount of class time allotted to individual work over the three implementations, the highest of which is just over 10% in year 3. In implementation one, Mrs. Miller rarely engaged her students in individual reflection during the middle of class. Instead, she tended to have students take a few minutes at the end of class to “jot down” their thoughts in their science journals. In the latter two implementations, however, Mrs. Miller made more time for individual writing within the class sessions. For example, upon the presentation of the launching question in year one, Mrs. Miller immediately had students share out their ideas. This is in contrast to the second and third opening day, when Mrs. Miller permitted some “individual” time for students to collect their thoughts silently prior to engaging in whole class discussion. To provide further illustration of this shift towards more individual work, Mrs. Miller administered a short formative-type assessment mid-way through the second implementation and a lengthy “final assignment” on the last day of the third implementation, both of which were completed by students individually.

I now turn to a discussion of the analyses of Mrs. Miller’s activity redirections.

5.2 Activity Redirections

While the vast majority of class time was spent discussing scientific phenomena, there were several additional activities in which the students engaged during the three implementations of the water cycle module. Specifically, the students: (1) designed, executed, and discussed experiments, (2) observed, described, and drew representations of classroom models and demonstrations, (3) listened to Mrs. Miller lecture, (4) generated responses to writing assignment prompts, and (5) organized specific terms within a pre-structured matrix. Although the “matrix” activity was unique to the first implementation, the other four activities were incorporated into at least two of the three implementations. Of all of these alternatives to discussion, the students were most often engaged in experimentation.

Activity redirections, as described in chapter 4, are Mrs. Miller’s attempts to shift the students from one activity to another. Table 5.2 displays the breakdown of Mrs. Miller’s activity redirections according to whether or not they were grounded in student comments (AC1 vs AC2). The second and third columns present the total number of instances of Mrs. Miller issuing an AC1 or AC2 redirection. These numbers show that while the overall numbers of redirections were pretty consistent (between 11 and 14 per implementation), there were differences with respect to the types of redirections across implementations. Analysis showed that implementation 1 had relatively few AC1 in comparison to AC2 redirections, implementation 2 had many more AC1 than the first implementation and only 1 AC2 redirection, and implementation 3 had a moderate number of both AC1 and AC2 redirections in comparison to the other two implementations. These findings, while perhaps interesting, are actually somewhat misleading, however, as will be discussed below.

Some of the students’ “non-discussion” activities were rather short-lived, lasting for only a few minutes. Some activities, especially those involving experimentation, were of longer duration and extended through large fractions of one or more class sessions, however. During these more lengthy activities, Mrs. Miller tended to shift her students between small group and whole class modes several times over the course of the activity. Shifts from small group to whole class discussion, as described earlier in section 4.3, were never coded as activity redirections, since it was not possible to determine whether Mrs. Miller's shift was responsive to her students or not. Shifts back to small group activity following these whole class "interruptions" however, *could* be coded as separate activity redirections, depending on the nature of the shifts. Thus, a single round of extended experimentation could involve multiple activity redirections.

Table 5.2 *Activity Redirections Across Implementations*

Implementation	Total # of AC1[a] redirections	Total # of AC2[b] redirections	# of AC1 unique activities	# of AC2 unique activities
1	2	11	2	7
2	13	1	3	1
3	5	6	1	3

Note. Values in columns two and three = # of redirections during module implementation. Values in columns four and five = # of unique activities for which there is one or more associated activity redirection(s).
[a]Activity Connection 1 (AC1) = redirection is connected directly to student comments. [b]Activity Connection 2 (AC2) = redirection is not connected directly to student comments.

To illustrate, compare the two following scenarios (Figure 5.1), both of which consist of a round of class experimentation following an initial activity redirection moving students from whole class discussion (activity #1) to an experimentation activity (activity #2). In scenario #1, Mrs. Miller eventually shifts her students out of their small group experimentation in order to engage in a brief whole class discussion about housekeeping and logistical issues related to the experiment. She then returns her students to their small group work. The return shift from whole class discussion to small group experimentation, in this case, does not warrant an activity redirection, since there is no alternate activity in which the students engage during their brief reconvention as a whole class. Thus, there is only 1 redirection coded for the entire experimentation activity.

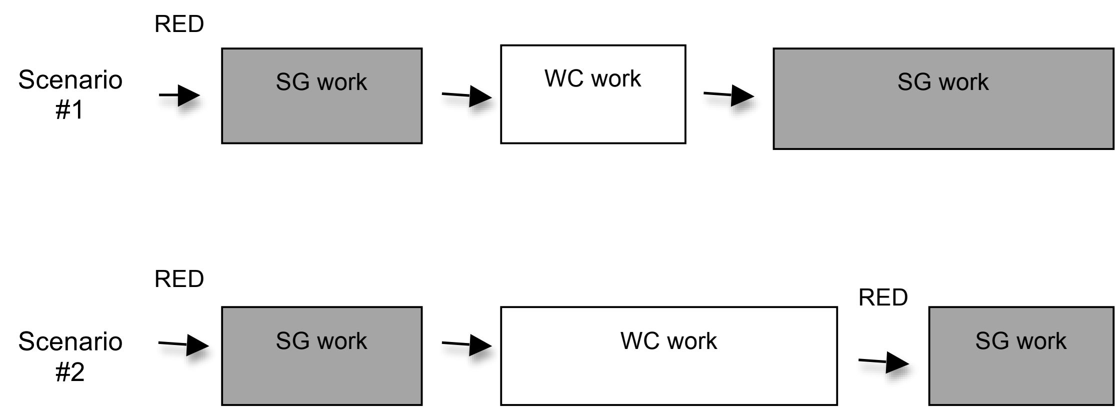

Figure 5.1 *Two Scenarios Representing Segments of Class Where Students Are Engaged In Experimentation, Both of Which Follow an Initial Activity Redirection (RED)*

In scenario #2, Mrs. Miller again shifts her students out of their small group experimentation in order to engage them in a whole class discussion. This time, however, the discussion concerns the scientific phenomenon that underlies their experimentation. The nature of this discussion is such that when the students are invited to return to their experimental work, it is clear that they are shifting from one type of activity (discussion of a scientific phenomenon) to another (experimentation). Thus, Mrs. Miller's bid to return the students to their small group work warrants an award of a second activity redirection code, resulting in a total of two activity redirections assigned to a single round of experimentation.

Returning to results presented in Table 5.2, if the numbers in the second and third columns are revised such they reflect each *round* of activity for which there is one *or more* redirections, the fourth and fifth columns are generated. While an examination of these results reveals similar patterns to those previously discussed for columns two and three, the trends are far less pronounced. For example, while the second implementation still had more rounds of activity associated with AC1 redirections than those associated with AC2, there is less of a dramatic difference between these two categories than when instances of activity redirections are considered. Similarly, the dramatic difference between AC1 and AC2 redirections in implementation one is diminished when the number of activities is instead considered.

While the distinction between instances of a redirection and rounds of activities associated with redirections may seem unnecessary, there were several occasions during the implementations where multiple AC1 redirections were associated with the same extended activity. It is arguable that several redirections that refer back to one activity (e.g. recurring shifts to *one* experimental investigation) warrant less recognition as distinct examples of Mrs. Miller being "responsive" in-the-moment as those redirections that are associated with disparate activities (e.g. shifts to *different* experiment investigations). It follows, then, that an examination and characterization of the unique *activities* associated with one or more AC1 redirections might be more revealing with respect to how Mrs. Miller was responsive to her students and whether she changed in this dimension of her practice.

Table 5.3 characterizes the unique activities associated with at least one AC1 redirection. It displays descriptions of all the unique AC1 activities for each implementation, the structural units in which the students worked during the activities, the day during the module in which the activity was initiated, and the duration of the activity. An examination of these results provides the basis for some claims about Mrs. Miller's practice across the three implementations.

Table 5.3 *Unique Activities Associated with AC1 Redirections Across Implementations*

Module	Activity descriptions	Session initiated and total duration
1	**Activity 1**: "*What would happen if-*?" A student wonders about the repercussions of a simple modification of the water cycle aquarium model demonstration set up in class. MM invites the students to consider the student's modification and make predictions as to the outcome. *Includes:* Whole class discussion only.	*Initiation*: **Day 12** *Duration*: A portion of one class session (< 10 min)
	Activity 2: "*I'm not sure*." Student expresses uncertainty regarding the origin of water dripping off a plastic bag of ice. MM invites the students to generate a "way to convince" him as to where the water originated. *Includes:* Small group work and whole class discussion.	*Initiation*: **Day 13** *Duration:* The majority of one class session (40 min)
2	**Activity 1**: "*I see you… making observations… In each of these examples we've talked about- How do we know evaporation is occurring? And how might we show that?"* After the students spontaneously began sharing different experiences they've had with evaporation, MM asks the students to generate experiments to show evaporation. *Includes:* Individual work, small group work, and whole class discussion.	*Initiation*: **Day 3** *Duration:* Portions of 7 class sessions (6 h)
	Activity 2: *"…Dry ice. It just goes from a solid to a gas because of how it's made."* During a discussion about evaporation of water, a student introduces the phenomenon of the production of "fog" from dry ice. The next session, MM brings dry ice for the students to observe and connect with their observations/ experimental conclusions regarding water evaporation. *Includes*: Individual work, small group work, and whole class discussion.	*Initiation*: **Day 9** *Duration:* Portions of 2 class sessions (1.5 h)
	Activity 3: "*C was…pondering that bag."* Following a session where students observed water dripping off bags of ice (an activity initiated by MM), MM takes two different students' suggestions and introduces alterations to the initial experimental procedure. *Includes:* Small group work and whole class discussion.	*Initiation*: **Day 14** *Duration:* The majority of one class session (40 min)
3	**Activity 1**: "*We should maybe test it."* A student raises a question (Does only water evaporate, or do other liquids evaporate too?) that results in a debate that endures for multiple class sessions. A student proposes testing possible explanations, a proposal which MM takes up with the class. *Includes*: Individual work, small group work, and whole class discussion.	*Initiation*: **Day 7** *Duration:* Portions of 4 class sessions (3.5 h)

Note. MM = Mrs. Miller.

First, while all three implementations included at least one activity that was grounded in student comments (i.e. one activity that involved at least one AC1 redirection), differences among the implementations existed with respect to the timing and duration of the activities. The two activities associated with AC1 redirections within the first implementation, for example, both took place in the last few days of the implementation (Day 12 and 13 of the fourteen day module) and lasted for relatively short periods of time. The first of these activities, in particular, was short-lived, enduring for less than ten minutes in total. In contrast, the AC1 activities in the second and third implementations of the module tended to be lengthier, often extending beyond a single class period. In fact, both years 2 and 3 included at least one AC1 activity that lasted for more than three class sessions. Furthermore, most of the AC1 activities in the second and third implementations were initiated at the beginning and/or middle of the implementation, as opposed to exclusively being initiated at the end of the module, as was the case for the first implementation.

Second, of the two AC1 activities that took place in the first implementation, only one included opportunities for students to work in small groups and neither provided time for individual reflection and summary. In contrast, all four of the AC1 activities that occurred in the second and third implementation included small group work as well as whole class discussion. Furthermore, three of the four also allowed time for individual reflection. The increased time allotted for individual work as part of AC1 activities in years 2 and 3 is consistent with the general finding of increased percentage of class time devoted to individual assignments (see Table 5.1).

There are two additional points worth mentioning with respect to an analysis of Mrs. Miller's activity redirections. The first of these is that with one notable exception, all of Mrs. Miller's AC1 redirections seemed to originate directly from comments made by single students. The AC1 redirection associated with activity #1 during implementation 1 (see Table 5.3), for example, followed student (Andre) wondering what would happen if the plastic wrap was removed from an aquarium model of the water cycle, and the AC1 redirection initiating experimentation in the third implementation was a response to student (Nathan) proposing to "test" other students' explanations. The one AC1 related activity removed from this general pattern, however, was the lengthy experimental activity that took place during implementation 2. Rather than responding to a single student's question or comment, Mrs. Miller based the redirection on her recognition of a general "shift" in the manner in which her students collectively were engaging with the phenomenon of evaporation during whole class discussion.

Transcript 5.2a [2.3.33:31 – ***bold italics typeface*** indicates redirection]

Mrs. Miller: I see a change happening in the room. I see something happening that I want to comment on. I'm noticing now that … instead of talking about the whole Earth and everything out there, and this is how it all happens, and the ocean and all that. You guys are starting to talk about examples- From observations of real life. And let me, let me point out what we've talked about. John started with the terrarium- that Beth also saw. And that the terrarium seemed to "feed itself," is what you said… Then, someone else mentioned the water bottle- with- drops up at the top in the morning…Tonya said something about the h- water bottle that blew up on a hot day. Right? Caren mentioned the soap bubble… There seems to actually be a liquid forming on the bottom of that bubble, and that when the bubble pops- it- sprinkles down. … Ronald actually talked about a discussion of using the book. And then, we brought out the two bottles that Michael mentioned that is supposed to be showing methane gas… Here's what I see…Here's my next question. I see you guys making observations- to help with explanations of what's going on. So I think I'm ready for the next question….***In each of these examples we've talked about- How do we know evaporation is occurring? And how might we- show that? In an experiment? How might we show that in an experiment?*** Does that make sense to you? You guys- Did you guys notice too how the conversation changed, though? [Students: Yeah.] So, now you guys all got some ideas of things going on. We've got our water bottle. We've got this. We've got that. We've got the other thing… What could you do as an experiment?

In this classroom excerpt, Mrs. Miller attempts to shift her students from whole class discussion (activity #1) to small group experimentation (activity #2). Prior to making her bid, however, Mrs. Miller shares with her students that she's noticed that they've collectively moved from more abstract explanations for "how it all happens" (lines 2 and 3) to examples and observations from their "real life" (line 3 and 4). She then lists several of their recent comments that involve tangible examples and/or experiences they've had (lines 4 – 11). These comments provide the foundation for her "next question" (line 11), where she ultimately invites the students to reconsider their examples and think about how they might use them to show evaporation occurs "in an experiment" (line 14). Thus, it appears that Mrs. Miller's bid to shift her students from whole class discussion to small group experimentation is directly connected to a shift she recognized in her students' comments. During her debriefing interview later that day, Mrs. Miller's further supported such a link.

Transcript 5.2b [DBRF 2.3.00:15 – italics indicates speaker's emphasis]

Mrs. Miller: I loved how the conversation- They were still talking big…big, big- things out here- (gestures outward, expansively) and … evaporates…The conversation changed. They started talking about things in real life. What they've *observed*. And as I noticed that, *now* they're getting to a point where, I think they could actually come up with an experiment. So as we shared those ideas, OK you got real life. You got real life. Ho- How does that show that evaporation is occurring? **…** So, what do you want to try? So, I think that was a good way to- just go with those guys.

Mrs. Miller's observation that her students switched from talking about "big things" to "things in real life" (lines 1-3) provided a foundation from which to invite them to further their inquiry through experimentation. Such a shift seemed to Mrs. Miller as "a good way to just go with those guys" (line 6).

While this “collective” activity redirection is arguably different than the redirections that take up a single student’s idea, this redirection certainly appears to be responsive to the students’ comments and, as such, warrants an AC1 code. I take up this example again in my discussion of the lifetime of student ideas in section 5.4.

The second discussion point concerns the dramatic drop in the number of AC2 related activities after the first implementation. As mentioned previously, Mrs. Miller experienced significantly more stress and uncertainty during the first implementation in comparison to the second and third. During our debriefing interviews following these class sessions, Mrs. Miller often expressed frustration at not knowing what to do and her need to go home and plan. These nightly preparations often involved online research and textbook reading about topics and issues that the students had raised during the day’s discussions. The knowledge gleaned from these sources, as well as her previous knowledge about the FOSS water cycle curriculum, often structured her agenda for the subsequent class session. These lesson plans occasionally included different “activities” in which to engage her students; activities that, when initiated, were marked by AC2 redirections. Mrs. Miller’s tendency to “plan” these types of activities and lessons lessened dramatically in the second and third implementations, as she grew in her understanding of her students’ capabilities and her role in promoting their inquiry. Thus, her AC2 redirections decreased after the first implementation.

Activity redirections: Conclusions and (possible) implications

The activity redirection results seem to permit three conclusions to be drawn. First, Mrs. Miller issued activity redirections that moved her students from whole class discussion to a variety of different activities, most often experimentation, during all three implementations of the water module. Second, Mrs. Miller issued AC1 and AC2 redirections during all three implementations. Third, Mrs. Miller tended to initiate activities associated with AC1 redirections earlier and for longer duration (e.g. multiple class sessions) in implementations 2 and 3, when compared to implementation 1.

The fact that Mrs. Miller incorporated at least one AC1 activity in each of the three implementations suggests that she was willing and able to listen to her students' ideas as they shared them during discussion *and*, at times, respond to their ideas by shifting the course of further activity. The fact that she did so earlier and for longer periods of time in the second and third implementations, however, raises questions as to (1) whether she grew more capable of inventing activities that could respond to her students' comments, and (2) whether she grew more willing to incorporate shifts to such activities and let them play out, during the latter implementations. While it is beyond the scope of this study to answer these questions, such questions certainly provide bases for further consideration and later work.

5.3 Focus redirections

As mentioned in the early paragraphs of this chapter, Mrs. Miller and her students spent the majority of their time during the water cycle module in whole class discussion. The topics broached during these discussions included, but were not limited to: clouds, lightning, fog, evaporation, condensation, and rain. While some of these topics endured for the briefest of class intervals (e.g. one or two talk turns), others extended across multiple sessions. Shifts *between* topics were often prompted by Mrs. Miller issuing focus redirections to her students. This section explores the instances and frequencies of Mrs. Miller's focus redirections.

Focus redirections: Results for first tier codes

Table 5.4 displays the total number of focus redirections and provides a frequency breakdown for the five first-tier focus redirection categories: FC1 (focus connection #1: topic grounded in student comments), FC2 (focus connection #2: revisiting previous topic), FC3 (focus connection #3: new topic), MEX (more examples/explanations), and HLD (hold off giving more examples/explanations). A comparison of the three implementations yields a number of noteworthy similarities and differences. I begin by describing the results that were consistent across implementations, after which I highlight the differences.

Table 5.4 *First-tier Focus Redirections Across Implementations*

Implementation	Total # of focus redirections	Standardized focus instances (# / hr whole class discussion)	Focus connection 1 (FC1)	Focus connection 2 (FC2)	Focus connection 3 (FC3)	More examples (MEX)	Hold off (HLD)
1	287	32.45	.624	.210	.059	.094	.011
2	180	19.81	.511	.194	.083	.183	.028
3	348	32.80	.644	.207	.060	.080	.009

Note. Values for FC1, FC2, FC3, MEX, and HLD are given in frequencies (decimal fraction of total number).

Overall results of the focus redirection analyses suggest that focus redirections were relatively common occurrences across implementations, with an average 12 or more redirections per class session. Additionally, all five categories of focus redirections were represented to some degree during all iterations of the water cycle module. Redirection frequencies show that there was a higher proportion of FC1 redirections than any other focus redirection type, with the second most common type of redirection being FC2. The two least frequently encountered focus redirections across implementations were FC3 and HLD, which accounted for less than 10% and less than 3% of focus redirections, respectively. Collectively, these results show that over seventy percent of Mrs. Miller's focus redirections reflected a degree of responsiveness to her students across implementations, either as responses to student comments in the moment of instruction (FC1) or attempts to revisit previously discussed topics (FC2). In contrast, fewer than ten percent of Mrs. Miller's focus redirections in all three implementations reflected an attempt to shift her students' attention to novel and/or unrelated topics (FC3).

While several patterns emerged from the data that were consistent across implementations, differences existed as well. The total number of instances of focus redirection, for example, differed dramatically across implementations. Results showed that implementation two had the fewest redirections (180), while implementation one had considerably more than implementation two (287), and implementation three had almost double the number of focus redirections as compared to implementation two (348). Prior to drawing conclusions from these data, however, it is necessary to consider the amount of time students spent in whole class discussion. Mrs. Miller's class spent less time in whole class discussion during the second implementation than in the first and third (see Table 5.1 in section 5.1), potentially accounting for the decrease in focus redirections (e.g. less whole class discussion would necessarily result in fewer instances of redirections).

To explore this possibility, focus redirection raw counts listed in Table 5.4 were normalized by dividing the number of redirection instances by the amount of time Mrs. Miller's students spent in whole class discussion. While this standardization process generated nearly equivalent numbers for the first and third implementation (32.45 vs. 32.80 redirections per hour of whole class discussion, respectively), it was unable to generate a similar outcome for year two (19.81 redirections per hour of discussion). Thus, time spent in whole class discussion did not seem to fully account for the number of instances of focus redirections. It appears that Mrs. Miler's focus redirections practice did change across implementations, with Mrs. Miller issuing far fewer focus redirections during implementation two than implementations one and three.

Examination of the different focus redirection frequencies reinforced the claim that Mrs. Miller's practice in the second implementation differed from that of the other two implementations. Analysis of implementation two yielded a lower proportion of FC1 codes (approximately 51% of all focus redirections) in comparison to the other two implementations (62% and 64% for implementations 1 and 3, respectively). Additionally, analyses showed that the highest percentage of MEX redirections occurred during implementation 2 (approximately 18%), while the other two implementations had approximately half this frequency. Pearson's chi square test results confirmed a significant difference across the types of redirections over the three implementations (Chi square statistic: 20.9, $p<0.01$, $df=8$). Interestingly, if the second implementation is excluded from the chi square analysis, no significant difference between implementations one and three is found (Chi square statistic: 0.50, $p>0.05$, $df=4$). The results suggest that while change did occur in Mrs. Miller's practice with respect to redirections across the three implementations, the change was neither linear nor monotonic.

Focus redirections: FC1 codes

As mentioned above, FC1 redirections were the most common focus redirections issued by Mrs. Miller across all three implementations. Table 5.5 displays the FC1 redirection totals and provides a frequency break down across the five FC1 categories: MIN (minimal connection with student comment), MOR (elaboration of student comment), CON (consider and/reason about student comment), TRM (explanation or identification of a scientific term or phrase), and REP (repetition of student comment).

Table 5.5 *Focus Connection 1 (FC1) Redirections Across Implementations*

Implementation	Total # of FC1 instances	Standardized FC1 instances (# / hr whole class discussion)	FC1 Minimum (MIN)	FC1 Elaborate (MOR)	FC1 Consider (CON)	FC1 Term (TRM)	FC1 Repeat (REP)
1	179	20.24	.453	.188	.306	.053	.053
2	92	10.13	.391	.109	.370	.130	.000
3	224	21.11	.541	.170	.266	.023	.028

Note. Values for different FC1 codes are given in frequencies (decimal fraction of total number).

Overall results showed that the second implementation of the water cycle module had the fewest number of FC1 redirections, both in terms of absolute numbers (92) and when standardized for the amount of time spent in whole class discussion (10.13 per hour whole class discussion). This was unsurprising given that, as described in the previous subsection, implementation two had the lowest number of instances of focus redirections in total. In contrast, analyses of the first and third implementations yielded a similar number of instances of FC1 redirections, especially when time spent in whole class discussion was taken into account (20.24 and 21.11 per hour whole class discussion, respectively). These values were approximately double that from implementation two.

An examination of the types of FC1 redirections produced several findings. First, MIN was the most frequently encountered type of FC1 redirection in all three implementations of the water cycle module, with the CON code awarded the second most frequently. Overall, these two codes accounted for between 75-80% of all of the FC1 redirections issued by Mrs. Miller across implementations. In contrast, TRM and REP were considerably less frequently encountered in the data set, jointly accounting for less than 15% of FC1 redirections in each of the implementations. Interestingly, the third implementation of the module had the highest frequency of MIN redirections of the three implementations, while the second implementation had the lowest frequency of this code. The third implementation also had the lowest frequency of CON and lowest *combined* frequency of CON and MOR codes in comparison to the other two implementations. Pearson's chi square analysis of the FC1 redirections confirmed a significant difference across the three implementations[14] (Chi square statistic: 22.0, $p<0.01$, $df=6$). Similar to the test described in the previous subsection, however, if the second implementation is excluded from the chi square analysis, no significant difference between implementations one and three is found (Chi square statistic: 4.58, $p>0.05$, $df=3$).

Taken together, these results provide fodder for reflection and discussion. The fact that the MIN and CON codes are more commonly found throughout the data set is not completely unexpected. These codes, to a large degree, reflect differing teacher objectives and goals. For example, MIN redirections, especially when they occur in a "stepping stone" series, suggest an intention on the part of Mrs. Miller to lead her students to specific content objectives or goals. In contrast, CON redirections encourage students to consider and reason about each other's observations and explanations. Such redirections reflect an intention that Mrs. Miller would like her students to listen to, develop, and learn from one another's ideas. While a deep exploration of Mrs. Miller's goals and objectives is beyond the scope of the current study, Mrs. Miller did repeatedly refer to having both content and "social" discussion goals during debriefing interviews and professional development sessions throughout the three implementations. Thus, it is unsurprising that she would issue large numbers of these two types of redirections (CON and MIN).

A somewhat surprising outcome was that Mrs. Miller issued a higher relative frequency of MIN and a lower combined frequency of CON and MOR in the third implementation. With additional time and experience implementing the open and flexible nature of the water module, one might have expected Mrs. Miller to become "more responsive" to her students and, thus, issue relatively more CON and MOR redirections to encourage her students to build on each other's ideas in the service of inquiry. Instead, the findings from the FC1 redirection analysis suggest that Mrs. Miller was less highly responsive to her students in the third iteration of the water cycle module than in the first two implementations, since the frequencies of these two "highly responsive" codes dropped and the frequency of MIN redirections increased.

Such redirection results might suggest that Mrs. Miller was becoming *less responsive* to her students' thinking over the course of the three implementations. Or, it could be argued that Mrs. Miller's responsiveness to her students' thinking fluctuates in response to factors unrelated to time or experience. While such interpretations of the data could certainly be made, I instead contend that these numerical data only capture a small piece of Mrs. Miller's change. A *closer* examination of the nature of Mrs. Miller's redirections, specifically that of her highly responsive redirections (e.g. *When* does she issue CON and MOR bids? *What happens* after such bids have been made?), reveals a more profound picture with respect to Mrs. Miller's change in responsiveness. In order to engage in such a deep examination of Mrs. Miller's practice, however, it is first necessary to consider the notion of the "lifetime" of a student idea.

5.4 The "lifetime" of an idea

The previous two sections described results that indicated that Mrs. Miller's practice changed with respect to her redirections. These changes, however, did not seem linear. These changes also did not necessarily seem consistent with prior expectations. If some of the redirections are more closely examined, however, then a slightly different picture of change takes shape. The following section characterizes the concept of the "lifetime" of a student's idea and how redirections can serve to perpetuate that lifetime. By exploring the redirections associated with higher levels of responsiveness (i.e. CON, MOR, AC1) and how they may serve to extend the "lifetime" of student ideas, a richer and more productive characterization of how Mrs. Miller's practice changed over the course of the three implementations is generated.

A “lifetime” of a student’s idea

The lifetime of a student idea consists of what happens *after* a student proposes an explanation, shares an interesting idea or experience, or raises a scientific question. For sake of clarity, I shall, from this point on, use the phrase “student idea” broadly to include any student issued observation, explanation, suggestion, experience, question, or phenomenon. The lifetime of a student idea may extend no further than his or her talk turn, or it may extend through several exchanges and be further elaborated and developed during considerable conversation. While there are several factors that may prolong or limit the discussion of student ideas (e.g. students’ interest, time left in the class session/module, Mrs. Miller’s agenda), one move that Mrs. Miller can make to potentially perpetuate discussion of a student idea, and thus extend its lifetime, is issuing a redirection in response to the idea. By taking up a student idea and encouraging her students to shift their attention to that idea, Mrs. Miller can help to promote its consideration and development. Thus, the student ideas that ultimately have long lifetimes are often a direct result of Mrs. Miller having issued one or more highly responsive redirections.

When a student shares an idea, several things can potentially happen. First, the idea can be ignored or dismissed lightly by both Mrs. Miller and her students. A second possibility is that other students take it up for further discussion either immediately or at some later point, without interference or intervention from Mrs. Miller. Third, Mrs. Miller may pursue the idea by asking one or more follow up questions of that student. Finally, Mrs. Miller may follow the idea by issuing a redirection, attempting to shift her entire class’s attention onto that student’s idea. If Mrs. Miller does indeed follow a student's idea with a redirection, there are several possible pathways that can be taken once the redirection is issued (see Figure 5.2). These possibilities warrant further elaboration and exemplification.

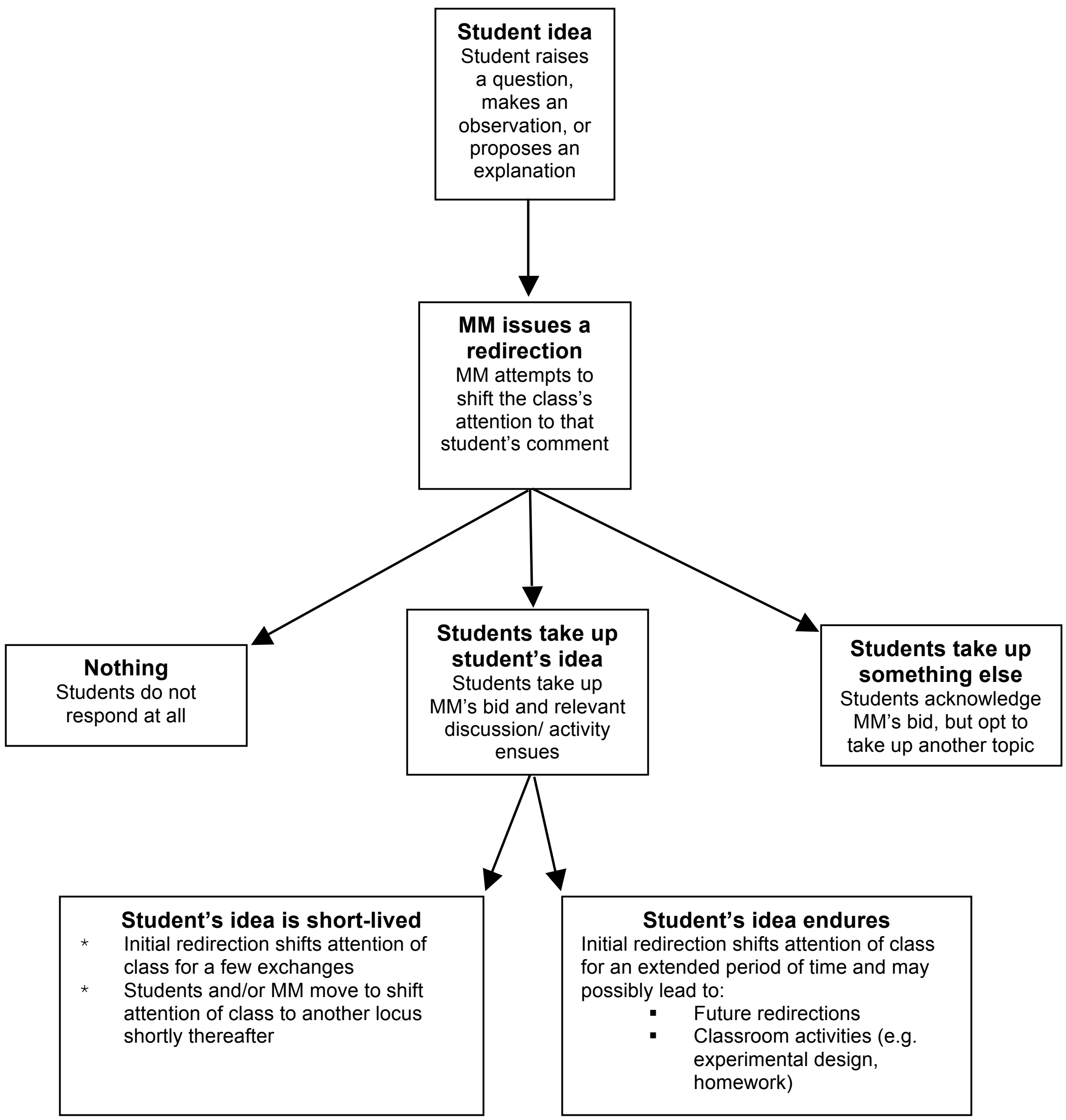

Figure 5.2 *The "Lifetime" of a Student's Idea: Trajectories Following a Redirection*

One possible outcome following a redirection issued by Mrs. Miller, for example, is that her students may choose *not* to respond to her redirection at all. In this case, Mrs. Miller's students remain silent and/or a pause ensues in the conversation. A second possibility is that the students respond, but in a manner inconsistent with Mrs. Miller's bid. The students, instead, opt to take up a different topic of conversation.

Examine the two excerpts of transcript below, both of which illustrate "unsuccessful" redirections.

Transcript 5.4a [2.13.56:56 – ***bold italics*** typeface indicates redirection]

Beth: I think when fog is going on the side of the bag it might be because of how cold it is. Because it's like on a window like when it's really cold outside, you feel the window and it's cold. And so when you breathe and go, "Hah," your breath is really hot and you can see faded fog on the window. So I guess that's like when your hand has heat, so when you touch it, it gets fog onto the bag, that's what I'm thinking.

Mrs. Miller: ***So everybody heard what Beth had to say, any comments about that?*** (pause) Michael, you have a comment about what B just said?

Michael: No. (pause)

Mrs. Miller: Final comment [for the class discussion], Ronald?

Transcript 5.4b [1.1.33:36 – ***bold italics*** typeface indicates redirection]

Ken: If you leave out like a soda or some kind of wine, will it still evaporate? Like fast? Or is it just wat-

Mrs. Miller: So, you're asking about water. Will substances other than water evaporate. I don't know. ***Does someone have a comment about that?*** (Matthew raises his hand.) Matthew? Do you have a comment about that?

Matthew: Well, not *that*. But I do disagree that all water has to evaporate, because … down in the trenches- Down in the salt water trenches, where no sunlight can reach? It- I don't think that- that will ever even go…

In Transcript 5.4a, Mrs. Miller invites the students to consider and discuss Beth's connection between fog appearing on the outside of a baggie of ice and blowing hot air on a car window (lines 5-6). She ultimately calls on Michael to respond, although he does not take her up on her offer. No other students take up the invitation, and Beth's idea is dismissed.

In Transcript 5.4b, Mrs. Miller issues an invitation for her students to comment on a paraphrase of Ken's question, "Will substances other than water evaporate?" in line 2. However, when she calls on Matthew to this effect, he takes up a different issue (line 5). The scenarios represented in Transcripts 5.4a and 5.4b consist of Mrs. Miller responding to her students' ideas by placing them on display for the rest of her students to examine via an FC1 CON redirection. Neither case, however, results in the students actually taking Mrs. Miller up on her offer. Thus, the lifetime of both of these students' ideas ends at the completion of Mrs. Miller's talk turn.

In contrast to the segments presented above, there were many occasions when Mrs. Miller's students successfully shifted in accordance with her redirections. Some of these shifts were "short-lived," as when students discussed the student idea for only a few talk turns beyond the initial redirection. In such cases, Mrs. Miller's students take up the student's idea only to shift their attention to another topic soon thereafter because: (1) a student raises a new question or topic, (2) the topic fizzles out in favor of the class discussing related and/or adjacent topics, or (3) Mrs. Miller issues a second redirection.

The following transcript excerpt illustrates a successful redirection that is quickly cast aside in favor of a broader, and potentially more accessible, topic. The excerpt follows a lengthy discussion where the students attempt to explain the presence of heavy cloud cover overhead. A few students raise the idea that the tilt of the Earth, which is linked to the changing of the seasons, somehow plays a role in producing this cloud cover.

Transcript 5.4c [2.9.09:59 – ***bold italics*** typeface indicates redirection]

Jimmy: I know one angle, the top angle of the globe, I don't know the bottom one. The top one is the Tropic of Cancer, then I don't know the bottom one, but it has to do with how the angle passes. Because when it spins, it hits one angle and then it hits the other angle.

Mrs. Miller: ***So how does the tilt, obviously you guys got this idea that the tilt is the reason why we don't get as much heat, but why does that cause what we see out there today?***

Martin: We aren't getting as much sunlight now, so it's not running through all the clouds. In the middle of summer, why there's not as many clouds is because the sun, it creates heat, so it basically just destroys the clouds. But now that we're going into winter, there's just enough sunlight that water evaporates, but then once it turns into clouds, there's not enough power of the sun for it to break through it.

Mrs. Miller: Hm. (pause) Go ahead, Jimmy, I was going to say something else, but go ahead?

Jimmy: I have to add on to Martin's statement. In summer, the sun's out almost the whole entire day, so it sucks up most of the water and forms clouds. By the time we get to winter, we form so many clouds that the sun can't poke through, and that's why we have the cold in the winter and the hot in the summer. And it rains in the spring.

Mrs. Miller: …Mary, go ahead?

Mary: I was thinking the reason is, because when the sun was showing, the water can evaporate; when the clouds are covering the sun, our experiments can't evaporate.

Mrs. Miller: So no evaporation can take place when it's cloudy like this? Is that what you're saying, I'm just asking, is that what you're telling me? (Mary nods) ***So (turns to the class) when it's a cloud cover like this, where it's total cloud cover, no evaporation occurs?***

The first redirection in this excerpt invites students to draw connections between the *tilt of the Earth*, a topic that had recently been touched upon by several students (including Jimmy in lines 1-3), and the *extensive cloud cover* that was visible overhead. Although Martin doesn't explicitly include "tilt" in his response to Mrs. Miller, his answer is consistent with her redirection, as he refers to sun destroying clouds in the "middle of summer" (lines 6-7) and the fact that they're "going into winter" when the sun has less "power" to break through the clouds (lines 8-9). Such mention of the seasons provides evidence that Martin shifted in accordance with Mrs. Miller's bid. Mrs. Miller then returns to Jimmy, who elaborates Martin's explanation by highlighting differences in cloud cover during summer and winter. Mary then shifts the conversation slightly to focus on evaporation and how cloud cover might affect that process. This comment actually is consistent with Mrs. Miller's initial task of having her students explain the cloud cover, rather than taking up her redirection to connect the Earth's tilt to that cloud cover. Mrs. Miller takes up Mary's comments and makes them the new focus for the class via a second redirection. Thus, while Mrs. Miller's initial redirection to shift her students' attention can be considered successful (i.e. Martin and Jimmy made the shift), the students' idea of "tilt" has a reasonably short "lifetime," since the topic remains the focus of attention for only a few talk turns before the discussion shifts toward Mary's focus on evaporation.

Some foci centered the class's attention well beyond a few exchanges. Transcript 5.4d exemplifies a redirection that successfully shifted Mrs. Miller's students' attention for a lengthier period of time (approximately fifteen minutes). The segment follows a student's (Henrietta) attempt to compare and contrast experimentation with a puddle versus a cup. She reasons that a puddle is more spread out than the water in a cup, and this makes a difference in terms of evaporation.

Transcript 5.4d [3.4.12:29 – ***bold typeface*** indicates redirection]

Mrs. Miller: (following up with student Henrietta) You're saying because the puddle is more spread out, what happens?

Henrietta: …You have more room to evaporate.

Mrs. Miller: It has more room to evaporate. (Turns to Larry.) ***What do you suppose she means by that, Larry? The puddle had more room to evaporate, what does that mean? What do you think it means?***

Larry: That when the puddle is thinner… It's like layers in the water, so it evaporates more. And the cup has the water higher and smaller layers, the water didn't evaporate.

Mrs. Miller: What do you mean by a layer, what does that mean?

Larry: The water that's evaporating in a layer.

Mrs. Miller: So the water evaporating in a layer, do you think?

Larry: Yeah.

Mrs. Miller: Oh, I never thought about. [Barry: Yeah.] (Turns to Barry) You said yeah. Why are you saying yeah to L? Does that make sense to you, that the water can evaporate in a layer (raises horizontal hand)? Why does that make sense?

Barry: Because the water is going to evaporate in a layer. So if you have water and it always stays straight like that (gestures horizontal). Then it's going to stay like this all the time, so it's (inaud) same amount.

Mrs. Miller: Oh, interesting. Xander? Can't hear you.

Xander: I was going to share what I did.

Mrs. Miller: ***Can we hold off on yours for a second, because I want to follow-up on what he's saying? Does anybody else want to comment about this whole idea that evaporation happens in layers****?*

Initially, Mrs. Miller invites Larry to consider and explicate Henrietta's comment that water in a puddle has "more room to evaporate" (line 5) via an FC1 CON redirection. Larry shifts his attention in accordance with Mrs. Miller's bid and takes up Henrietta's comment. In so doing, Larry proposes that evaporation occurs in layers (lines 6-7). Mrs. Miller pushes Larry to explain this idea further (lines 8 and 10) and then turns to Barry to continue the discussion (lines 12-14). Shortly after Barry's response, Xander attempts to shift the conversation elsewhere (line 19). At this point, Mrs. Miller stops Xander (and the rest of the class) from moving on by issuing a "hold off" (HLD) focus redirection (lines 20-21) in order to invite any additional thoughts on Larry's comment that "evaporation happens in layers." While this excerpt ends here, other students *do* take up this topic and relevant conversation ensues for several more minutes before shifting to a related topic.

Transcript 5.4d provides an example of a focus redirection (HLD) that ultimately helps to perpetuate the lifetime of a student idea (i.e. one that extends beyond a few exchanges). Mrs. Miller's initial CON redirection shifts her students to attend to Henrietta's comment, which prompts Larry to propose a "layer" model of evaporation.

The layer model provides the center of attention for a rich discussion that endures beyond a few exchanges, perpetuated in part by Mrs. Miller issuing a critically timed HLD redirection. Had Mrs. Miller not issued the HLD redirection, Xander would have shared his comment and the class would have not likely elaborated Larry's layer model.

Using the concept of "lifetime" to make claims about Mrs. Miller's change

An examination of the three implementations with a lens on the "lifetime" of student ideas reveals an interesting story of change in Mrs. Miller's practice. Prior to this discussion, however, a brief foray into what is meant by a teacher's "responsiveness" is warranted.

A teacher may respond to his or her students in-the-moment in several different ways, such as evaluating them or attempting to use the idea as a stepping-stone to reach specific content objectives (consistent with Pierson's (2008) low and medium level of responsiveness), or placing the idea up for possible consideration by the class (consistent with Pierson's (2008) higher levels of responsiveness). Characterizing a teacher's FC1 redirections represents one way of capturing this type of teacher responsiveness.

Alternately, a teacher may respond to student ideas by utilizing them as a foundation for class instruction *on a different day*, as when the teacher uses a student's idea as launching point for the next day's discussion. This type of "planned" responsiveness (i.e. using student ideas as the basis for future class discussion) can be viewed as different from the "in-the-moment" responsiveness (i.e. using student ideas as the basis for immediate discussion). While both types of responsiveness require the teacher to hear and make use of student ideas, the latter requires a teacher to attend, process, and respond to student comments *as they emerge*. Such a practice depends on a teacher's willingness to make an immediate decision to move in particular direction following a student comment. In contrast, the former strategy allows the teacher time to reflect upon student comments, process them, choose one or more that seem appropriate to pursue, and prepare how best to present them to the class. With these two forms of responsiveness in mind, I now return to a consideration of Mrs. Miller's three implementations of the water cycle module.

Implementation 1

Mrs. Miller's first implementation consisted of class sessions that, for the most part, contained isolated discussions that endured for a single session at most. While the foci of many of these discussions centered on student ideas, most of the initial ideas stemmed from student comments made during previous class sessions or via written questions or comments submitted to Mrs. Miller. For example, Mrs. Miller began the third class session with the question, "Which clouds cause lightning?" and Day 10 with "What causes rain?" both of which were questions raised by students during journal writing at the end of a previous class session. As described above, this practice represents a certain level of responsiveness to student ideas, for the ideas indeed form the context for further class discussion. However, the ideas are carefully selected via planning and preparation and, in Mrs. Miller's case, through discussion with others. (Mrs. Miller often selected the student's idea as a result of our debriefing sessions during the first implementation.) Mrs. Miller's in-the-moment responsiveness to her students during this implementation, however, was somewhat limited.

Discussions during implementation one regularly meandered to myriad topics of consideration. The students moved between topics fluidly, often without reaching consensus, resolution, or completion for any one area of focus before moving to the next. Many student questions were raised without pursuit or even acknowledgement; student explanations were proposed without consideration or evaluation. As an observer, it was difficult to follow the path of the numerous ideas as they emerged, even with copious notes.

Within these discussions, Mrs. Miller issued many FC1 redirections, of which nearly half were either CON or MOR. The results of most of these "highly responsive" redirections were short-lived, however, perpetuating discussions on student ideas for few exchanges at most. CON redirections, for example, often resulted in either an unsuccessful outcome (e.g. no response from students) or a "discussion" that concluded after a single response. While Mrs. Miller was able to respond to her students in the moment and take up their ideas, as evident by the presence of CON and MOR redirections, it seemed she was less capable of supporting and perpetuating subsequent discussion about these ideas with her students. Thus, Mrs. Miller's practice of responding to her students in the moment was limited in terms of extending and prolonging the lifetime of emergent student ideas.

Additional evidence to support this claim of response limitations on the part of Mrs. Miller came in the form of what I call "missed opportunities." Throughout the fourteen days of implementation one, there were numerous occasions where students posed questions, proposed explanations, or described phenomena worthy of consideration, pursuit, and elaboration. In short, the students raised ideas that held the potential for further inquiry. On many of these occasions, however, Mrs. Miller did not respond with an attempt to push for further clarification, elaboration, and/or exemplification. It is certainly arguable that it is neither possible nor necessarily desirable for a teacher to respond to every worthy student idea that arises during discussion. However, if a number of these productive explanations, models, or questions are simply acknowledged as contributions and/or are dismissed by the teacher, rather than offered up for additional consideration, these student comments can be considered to be *missed opportunities* for further inquiry. This seems to be especially the case if the larger context for the class discussion is an open and flexible module designed to allow the teacher to be "responsive" to his or her students' ideas.

The following two transcripts exemplify two different types of missed opportunities. The first consists of a student's explanation for what causes rain. The second consists of a student's proposal for how wind might affect the speed of evaporation.

Transcript 5.4e [1.10.05:03]

Mrs. Miller: Jasper?

Jasper: I think what causes rain, possibly, is that really, really high in the sky? The really high clouds are maybe- that there is ice in it? And then, maybe, like heat rises, and... the lower clouds? It falls into the lower clouds, and- maybe the heat hits the clouds and it releases the rain. By dropping it.

Tyron: It's too full, 'cause it can't- it can't hold any of the water any more. So it just, comes out as raindrops.

Mrs. Miller: Alright. Brandon?

(At this point, Brandon takes up a different topic, and Jasper's idea is dropped.)

Transcript 5.4f [1.7.49:06 – ***bold italics*** type signifies redirection]

Mrs. Miller: … Would you think that wind will affect the rate of evaporation?

Henry: Yes.

Mrs. Miller: Why?

Henry: Because it might keep the water cooler. I think, yeah, it would, and water being blown on by a fan would keep it cooler, so it would take more time to evaporate. Plus, I think if it were not really moving that much, then if it's not moving, then the sun can just beam down right on it, and just really focus its rays on it. But if it's moving, then that also makes it stop.

Mrs. Miller: So does that mean that it's going to evaporate faster?

Henry: Yeah, I think that wind, if we have a fan on a container of water, then that water would evaporate slower than a container that's not being blown on by a fan.

Mrs. Miller: ***Daniel, what do you think about that?***

(Students continue to debate whether or not wind and/or a fan would increase or decrease the speed of evaporation for a few minutes.)

Anthony: I disagree, because I went to Colorado, and I was at the river, and it was just steam, the river was steam.

Henry: Yeah, I'm not going to say it's not going to evaporate, I'm just saying I think that it would evaporate slower than some non-moving water such as a lake.

Mrs. Miller: So what I'm hearing is, we still have questions, and we're still not sure, we still have disagreement about things. (Mrs. Miller then introduces a different topic.)

In the first excerpt, 5.4e, Jasper proposes an interesting mechanism for how rain forms. He reasons that if really high clouds have ice (line 3) and if heat rises (line 3), then perhaps the heat melts the ice, which falls onto lower clouds and causes the rain to drop (lines 3-4). While this explanation is scientifically inaccurate, it is mechanistic and causal. Hence, it would potentially represent an explanation for further consideration by Mrs. Miller's students. Tyron immediately takes up Jasper's comment and attempts to extend it. Rather than attempting to perpetuate additional conversation on this student idea by issuing a CON or MOR redirection, however, Mrs. Miller acknowledges the students' contributions and calls on another student without drawing attention to Jasper's idea by issuing a redirection. Brandon subsequently takes up a different topic and effectively terminates the lifetime of Jasper's idea. While Mrs. Miller could have perpetuated further conversation, she allowed Brandon to comment on something else and, thus, shift the class in a different direction. Hence, this transcript segment illustrates an example of a "missed opportunity."

The second excerpt, 5.4f, reflects a different kind of missed opportunity. Henry reasons that wind and/or a fan might slow evaporation for two reasons. First, the wind itself cools the water. Second, the sun is less likely to beam directly onto water that is moving around. Mrs. Miller initially misunderstands Henry's explanation, asking him if he means that the water will evaporate faster (line 8). Henry, despite saying "Yeah," then restates that wind/fan would slow evaporation (lines 9-10). In contrast to the first excerpt, Mrs. Miller *does* issue a redirection to attempt to shift the students' attention to Henry's idea (line 11). As a result of this move, the students go on to elaborate and develop the idea for several minutes, with several students affirming Henry's claim. Others argue against this notion, however, citing increased evaporation from moving rivers as evidence (e.g. Anthony's observation of the Colorado River in lines 14-15). Rather than facilitate additional debate and/or discussion on the topic, Mrs. Miller opts to stop the conversation shortly thereafter: "So what I'm hearing is, we still have questions, and we're still not sure. We still have disagreement about things" (lines 18-19). She then moves the discussion in a different direction, sharing with the students what "experts" say about evaporation.

This segment of class discussion represents a missed opportunity, for two reasons. First, the topic of wind's effect on evaporation was consistent with previous discussions the students had had regarding other factors affecting evaporation. Secondly, the students were engaged in a heated debate and had reasonable arguments on both sides of the issue.

Thus, the topic seemed to merit extended discussion and, potentially, experimentation, although Mrs. Miller opted to shift the students' attention to a different locus.

Despite many missed opportunities in the first implementation, there were at least three noteworthy occasions where Mrs. Miller took up her students' ideas in the moment, invited additional students to comment upon them, and encouraged extended discussion and/or activity consistent with the ideas. Such occasions provide glimpses of Mrs. Miller developing the means, flexibility, and presence-of-mind to take up and extend student ideas in the moment during class.

The first of these occurred on the twelfth day of instruction, when a student (Tommy) described a phenomenon he'd witnessed on his ceiling and inquired as to why the phenomenon took place. Mrs. Miller immediately followed the query up with probing questions after which she offered the phenomenon up to her students for further comment via an FC1 CON redirection, "Say that again. I didn't get it. ***Maybe someone can help. Do you understand what Tommy is asking***? [1.12.19:26 – ***bold italics*** typeface indicates redirection]" During the ensuing discussion, Mrs. Miller moves back and forth between the original inquirer and other students, at times issuing other highly responsive redirections. It is clear by Mrs. Miller's comments during this discussion that she is trying to understand and respond to Tommy's idea and inviting her students to do the same. Although the entire conversation lasts for only five minutes, it is an excellent example of Mrs. Miller exhibiting in-the-moment responsiveness to her students via using strategic redirections. As a result of these redirections, the lifetime of Tommy's idea is extended and perpetuated through discussion.

The second noteworthy occurrence occurred later in the same class session, when a student asks what would happen if Mrs. Miller removed the plastic wrap affixed to the top of the aquarium “water cycle” demonstration. Although Mrs. Miller does not immediately take up the student’s suggestion, she later invites all of her students to make predictions as to the outcome of the plastic wrap’s removal (via an AC1 redirection) and subsequently removes the plastic wrap in order for the class to determine the answer.

The most compelling example of Mrs. Miller issuing a series of redirections that ultimately extended the lifetime of a student’s idea during the first implementation occurred on the second to last day of the module. Early in the session, a student (Jamie) expresses uncertainty regarding where water dripping off a bag of ice originated. Mrs. Miller quickly follows his confession with an AC1 redirection, inviting her students to design potential empirical methods to help Jamie to better understand the phenomenon. After a few minutes of small group discussions, Mrs. Miller reconvenes the class to share out potential procedures. Students communicate their ideas, and Mrs. Miller issues several CON redirections to engage her students in consideration of each other’s proposed experiments. Several minutes into the discussion, Mrs. Miller issues a MEX redirection inviting one final student to share an experimental idea.

Transcript excerpt 5.4g [1.13.23:36 - **bold *italics*** typeface indicates redirection]

Mrs. Miller: Okay. ***Who's got an idea that they want to share, because I really want to wrap this up, because I really want the time to go off in a different area if possible? Reina, did you and Jasper come up with an idea***?

Jasper: You get a cold water bottle. Then wipe it off, the water vapor, that was on it from before. And get a plastic bag that's hole-less.

Mrs. Miller: Holeless? I think we're creating new vocabulary here, too.

Jasper: Then you put the water bottle in the plastic bag, and then you see if the water. If the condensation- The water vapor condenses on the water bottle or the plastic bag.

Mrs. Miller: ***Does anybody have a question for Jasper about that idea?*** (points to student Mack) What's your question?

What follows this excerpt is an extensive exploration of Jasper's proposed experiment, where the entire class considers, develops, elaborates, and discusses modifications to Jasper's original protocol. Within this discussion, Mrs. Miller issues several additional CON and MOR redirections, which serve to encourage and nourish additional development of the experimental procedure. At one point, Mrs. Miller actually enacts Jasper's experimental set-up. An examination of Mrs. Miller's initial MEX redirection (lines 1-2) suggests that she originally intended to cut the discussion short and engage her students in a different discussion or activity ("…I really want to wrap this [discussion] up, because I really want the time to go off in a different area…") However, Mrs. Miller allows the discussion to go on for an additional fifteen minutes and *returns* to the discussion both later in the session and, briefly, the following day. Her AC1, CON, and MEX redirections all contribute to perpetuating the "lifetimes" of Jamie's initial statement of uncertainty, as well as Jaspers's subsequent proposal for an experimental means to help resolve that uncertainty.

The three examples described above provide evidence that Mrs. Miller is able to take up and respond to her students' ideas and questions *in-the-moment*, and foster extended discussion about those ideas and questions in order to promote further inquiry and understanding among her students in implementation one. All three examples occurred towards the end of the water cycle module (Days 12 and 13), however, and two of the three consisted of discussions that endured for less than ten minutes in sum. Hence, while they demonstrate that Mrs. Miller is capable of engaging in a higher level of responsiveness with her students, their limited time and number indicate room for growth.

In conclusion, despite Mrs. Miller issuing a high number of redirections in implementation one, there was evidence to suggest that she was rather limited in her ability to perpetuate the lifetime of her students' potentially productive ideas as they emerged during discussion. There were, however, occasional glimpses to suggest that she was capable of taking student ideas up in the moment and foster their consideration and elaboration. These occasions became more lengthy and frequent during the second and third implementations.

Implementation 2

Although there were fewer redirections issued by Mrs. Miller during the second implementation of the water cycle module (Table 5.4), there were more examples of Mrs. Miller's redirections serving to encourage, promote, and perpetuate discussions of specific student ideas. These examples occurred throughout the module implementation, in contrast to being found only at the end of implementation one. Furthermore, the discussions of specific student ideas in the second implementation often endured for large sections of class sessions and, a few times, extended beyond the confines of a single session. While it is impractical to provide descriptions and/or transcripts of all of the examples here, I describe two such occasions below, in order to help illustrate Mrs. Miller's change in practice from implementation one to implementation two.

The first example is taken from the second day of the second implementation. Mrs. Miller began the session by inviting students to share any "additional" thoughts about puddles and/or evaporation that they'd had since the previous class. Throughout the next several minutes of class, Mrs. Miller facilitates an animated discussion among her students as they discuss several comments and questions related to the "disappearing puddle" phenomenon. At one point, a student (Martin) raises a question about an experience he's had in the desert:

Transcript 5.4h [2.2.08:08 – italics indicates speaker's emphasis]

> **Martin**: … Once when I was out in the desert, I looked up in the sky into the light. There'd just be, just, little specks of- white. Then once it got over me, they're full sized clouds. You could see 'em. Like *Form*ing. They're, like, growing bigger and bigger by the second, and my question is- How do they grow so FAST?

The students then begin to grapple with Martin's question, proposing various explanations for why the clouds might have grown so quickly over the desert. The potential role of heat, humidity, and proximity of the mountains are alternately raised, considered, dismissed, and revisited. After several minutes, Mrs. Miller issues a FC2 redirection, inviting the students to specifically revisit a specific student's suggestion that the mountains somehow play a role in the formation of the clouds. Relevant discussion ensues where the students consider whether it might be possible for Martin's clouds to have moved around the mountains. After a short while, Mrs. Miller stops the whole class discussion and issues a FC1 CON focus redirection, inviting the students to work in small groups to devote their full attention to the phenomenon.

Transcript 5.4i [2.2.18:26 - italics indicates speaker's emphasis]

> **Mrs. Miller**: … I got an idea. I got this brainstorm. (claps hand) I think I need to see what you guys are talking about. So, I'm gonna put you in groups of four. So, put your hands down for a second. Because you guys *all* wanna say something. …'So, here's the question. I'm thinking- I'm visioning that this is gonna help us here. So. Kinda switching to clouds. Right? … You've got them coming up to the mountains. Something happens. But then there's clouds on the other side, (pointing to Martin) where Martin is in the desert, right? So. I think the question I want you to answer for me, is: What's happening from one side of the mountain to the other? What's going on

> with the clouds? And I'm going to give you some boards and markers, but I want you to talk about it first. What's *happening* with the clouds from one side of the mountain- How do they end up getting to the other side of the mountain?

The rest of the class session consists of the students developing, sharing, and assessing possible explanations for Martin's phenomenon.

In this example, Martin's original question regarding how clouds could form so quickly in the desert provided the foundation for the majority of a class session. While such a focus on a student idea could be considered similar to many of the conversations of the first implementation (e.g. the discussion of the question, "What causes rain?"), the primary difference lies in that Martin's question emerged *and was taken up by Mrs. Miller* during class. Mrs. Miller heard her students discussing Martin's phenomenon, recognized their comments and questions as a potentially rich and productive inquiry, and invited her students to make the phenomenon the focus of their explicit attention by issuing a series of redirections at that time. Thus, a student comment that could have been dismissed or simply fizzled out on its own, instead was highlighted, discussed, and elaborated, ultimately resulting in a long lifetime for the original student idea.

The second example is taken from the third day of the second implementation. Mrs. Miller began the class session by inviting the students to consider the question, "How does water get up to the clouds?" The students then are given time to individually record their thoughts, after which they engage in a lengthy discussion about their ideas. Mrs. Miller mediates the ensuing conversation by calling on different students to share their ideas, although she rarely issues comments of her own. While she occasionally probes her students with follow up questions, she predominantly allows the students to volunteer and elaborate their ideas without prompting from her.

Halfway through the hour-long session, Mrs. Miller stops the class to observe to the class that she's "seen a change happening in the room." Following this initial observation, she recounts to her students that she's noticed that they've shifted from discussing more theoretical, abstract explanations of evaporation to sharing more tangible, real-world experiences of the phenomenon (see Transcript 5.2a in section 5.2 for full text of this comment). She reviews several of their individual ideas and then asks her students, "How do we know- in each of these examples we've talked about- How do we know evaporation is occurring? And how might we- show that? In an experiment?" This AC1 redirection initiates a shift between discussing a phenomenon (activity #1) to experimentation (activity #2).

This second example illustrates Mrs. Miller's ability to hear her students' individual ideas and recognize a theme pervading those ideas. It is this observable pattern that she takes up and responds to, encouraging her students to pursue their ideas and experiences concerning evaporation further through experimentation. While Mrs. Miller's redirection does not necessarily serve to propagate an *individual* idea through a shift in discussion and/or activity (although several of the students do use previously shared ideas as foundations for experimentation), the bid does serve to perpetuate the lifetime of the *collection* of student ideas through empirical study and investigation. Hence, this move highlights a change in Mrs. Miller's ability to hear and respond to her students in-the-moment.

The two examples described above are representative of many situations that occurred during Implementation 2. Collectively, such cases suggest that Mrs. Miller was likely to respond to her students differently in Implementation 2 than she did during

Implementation 1. More specifically, there seems to be evidence that she was more likely to take up her students' ideas *as they emerged* during discussion in Implementation 2 and make them the focus for extended class discussion and activity. This is in contrast to Mrs. Miller's tendency to rely on preconceived plans or agenda items during Implementation 1.

While such examples suggest a change in Mrs. Miller's practice from Implementation 1 to Implementation 2, there were still several occasions where rich, scientifically interesting, and potentially productive student ideas were not taken up by Mrs. Miller. As described previously, Mrs. Miller issued far fewer focus redirections in the second implementation than the other two, both in terms of sheer numbers and number of instances per hour of discussion (see Table 5.4). Such results suggest that Mrs. Miller may have taken on less of an active role guiding the conversation, instead permitting her students to share and elaborate their ideas as they saw fit. In fact, there were many times where students proposed explanations or raised questions that were taken up and elaborated by others in the class, without Mrs. Miller needing to issue follow-up questions or redirections to promote more discussion. However, as with Implementation 1, there seemed to be a number of "missed opportunities," where Mrs. Miller allowed potentially rich student ideas to be cast aside, rather than focusing her students' attention on their elaboration and development.

The following transcript excerpt is taken from a discussion during the third day of Implementation 2 and consists of a series of several students' statements, all of which were acknowledged, but not taken up, by Mrs. Miller. The segment is embedded within a larger discussion of the mechanisms that underlie the process of evaporation.

Transcript 5.4i [2.3.17:03 – *italics* indicates speaker's emphasis]

Mrs. Miller: Why does it go from- *water*. I mean, we know what *water* is. How does it get from *this* (holds a water bottle) to a gas. That's what I asked… Caren? What are you thinking?

Caren: Like, uh- You say, "Steam on a stove." It's like tiny particles of water rising into the air. If you put your hand over it? It just collects on your hand, because- I mean, it's not just gonna disappear as soon it hits your hand. Jus' keep collecting and collecting. 'Til- you have a bunch of water on your hand. But, like, um- Heat from the sun- It, like, makes, the uh- water *light*. And re- like, really light. Because it- it's so *hot*, that it, like, takes away some of the water, making it very light. So, it floats up in the air, like mist.

Mrs. Miller: (pause) Woooowwww. Charlie.

Charlie: I know. I know that heat? Makes certain… molecules- expand? So, that's what happening with water. The heat's making them expand, but when they expand, they're the same weight, they're just taking up a lot more *room*. So, then- you have, basically a big cloud, but you just can't *see* it. And then, when the sun reflects off it, it makes that gas rise. But it gets colder as you go higher. So then- what happens- is- It-'ll condensates on the other molecules to form a cloud. And then, when the sun reflects off that, now it's bigger. So you can actually see it. (pause)…[discussion focuses on other topics a few minutes]

Mrs. Miller Wow. 'K. Laura? ...

Laura: Who was talking about the molecules? Was that Charlie?

Mrs. Miller: N. Yes. [Laura: Yeah.]

Laura: Well, what- what I think happens that the water molecules- when they heat up, they expand? And, they start- and they start- they expand (moves hands away from each other)? And start, like, flying around turning into gas? And then, gas rises? So, it rises up into the air. And then, um, then- it- when molecules get cooled down, they start moving *slower* and they- tend to *condense* more. So, that these [other?] water molecules. So, they evaporated, and then when they get higher up, it gets colder, so they come together? And condense? And then they form a cloud. (pause)

Mrs. Miller: Huh. Huh. (calls on another student)

The segment transcribed above includes three students' explications of evaporation, all of which provide several points of entry for additional comment. Caren, for example, proposes that the heat from the sun makes the water very "light" which causes it to "float" into the air like "mist" (lines 6-7), and Charlie suggests that expanding molecules take up "a lot more room," which generates a "big cloud" (lines 11-14). These words and phrases beg for clarification, interpretation, and elaboration and prompt questions such as: Why does the sun make the water light? Why do the "lighter" molecules float? Why do they float? How far do they float? How do expanding molecules produce a cloud? Is this “cloud” the same as the white, puffy clouds we see in the sky? Mrs. Miller does not ask any of these questions, however. Rather, she acknowledges her students (e.g. “Wow” in lines 8 and 15, “Huh. Huh.” in line 24) and provides room for others to comment.

The excerpt, which is representative of numerous discussions that occurred throughout Implementation 2, was selected to highlight several points. First, this excerpt demonstrates that the students had rich and productive ideas about evaporation from which to build. Secondly, this segment provides illustration of Mrs. Miller’s tendency to remain silent during the second implementation and simply acknowledge student contributions rather than probe them further or issue redirections to make these explanations the focus of the class’s attention. Lastly, this piece shows that the students were listening to each other and capable of elaborating each other’s comments, despite limited participation in the discussion by Mrs. Miller. Laura, for example, extends Charlie’s proposal that molecules expand and rise when they are heated to account for how they might later condense to form a cloud. While Mrs. Miller made room for her students to share and elaborate each other’s ideas, the fact that Mrs. Miller issued fewer redirections may have limited the lifetimes of these explanations, as rich as they might be.

Implementation 3

The third implementation differed from the first and second in that there were numerous occasions where Mrs. Miller took up students’ comments, invited her class to examine them via a redirection, and fostered that examination with additional probes and/or redirections. Similar to the second implementation, these occasions were spread across the duration of the implementation. What particularly distinguishes the third from the second implementation, however, is that these occasions were more frequently found on a day-to-day basis. As described earlier, redirections were much more common occurrences during the third implementation than in the second, with more instances of FC1 redirections than in either of the other implementations. The elevated frequency of focus redirections is indicative of Mrs. Miller's willingness to take a more active role in discussion and attempt to shift the conversation in-the-moment. Additionally, the most remarkable example of an extended lifetime of a student's idea occurred during Implementation 3.

In order to illustrate the level of responsiveness shown by Mrs. Miller during Implementation 3 and the manner by which this responsiveness served to prolong the lifetime of student ideas, I share three classroom examples below. All three examples are far too lengthy to provide transcript excerpts in their entirety. Hence, for practical purposes I include segments here that highlight critical aspects of each of the three discussions.

The first example took place on the third day of the third implementation. Mrs. Miller began the session by inviting students to review their conclusions from the previous day's discussion. She then asked her students where they thought the class should go next. One student, Nathan, responded that the class should create a puddle outside and observe what happens to it. Tyrella then described an alternative investigative procedure.

Transcript excerpt 5.4j [3.3.09:36 - ***bold italics*** typeface indicates redirection]

Mrs. Miller: Alright, so what are we thinking?... Where we are now, what we need to do next? Just what's your thinking about, Nathan?

Nathan: I think we should maybe make a puddle…Maybe put a cup outside.

Mrs. Miller: Say what?

Nathan: Maybe pour water on the concrete.

Unknown Student: It would dry just great.

Mrs. Miller: ***Does anybody have a comment about what Nathan is saying***, Tyrella?

Tyrella: You could take a cup, put water in it, and then get a Sharpie® and write where the water amount is. And then the next day, you could see how much evaporated.

Mrs. Miller: Wait a minute, let me get this, I don't have it. So you want to take a cup, put water in it, and then do what?

Tyrella: And then get a Sharpie and then write where the water level is, and then you can see how much water evaporated.

Mrs. Miller: And why are we doing that?

Tyrella: To see how it works.

Mrs. Miller: How what works?

Tyrella: Evaporation.

Mrs. Miller: Oh, interesting, Emma?

Emma: You could make a puddle by pouring some water on the concrete. And then observe that daily, observe that a few times that day.

Mrs. Miller: So I want to hear what Nathan has to say, and then I want to come back to something, Nathan?

Nathan: It just rained, so we could look at puddles right now, there's a puddle right there (points window). So maybe we could stare at it for a while and then observe it.

Mrs. Miller: So stare at it for a while (laugh). What did you want to say, Mary?

Mary: I think Emma's idea to make a puddle is better. We could just put it in a cup, because that could just have evaporation. Because we could sometimes just step in a puddle, or something else could happen to a puddle besides just evaporation.

Mrs. Miller: ***So let's back up to what Tyrella said, and let's weigh that against what Emma says…This is really interesting, because Tyrella went from puddle outside, somehow you made this leap from the puddle to the cup. Can you tell me what made you think of that?***

This segment includes two critical redirections. The first, an FC1 CON redirection, invites the students to consider and comment upon Nathan's initial suggestion to "make a puddle" (suggestion: lines 3 and 5, redirection: line 7), after which Tyrella describes a rather detailed procedure for measuring evaporation from a cup of water. The second redirection takes place after a few more students (Emma, Nathan, Mary) have made additional empirical suggestions and consists of an invitation to revisit (FC2), elaborate, and compare two experimental methods (lines 29-31). What follows this transcript excerpt is an incredibly rich debate concerning which would be better (i.e. more informative, realistic, and/or practical) to observe: a puddle or a cup. The students ultimately consider affordances and limitations of the two alternatives for almost forty-five minutes, until Mrs. Miller suggests that the students "try something at home."

In contrast to what might have occurred during the previous two implementations, Mrs. Miller did not simply acknowledge the students' contributions, nor did she allow students to meander away from discussing these two empirical suggestions. She also did not "tell" her students which method might be better and move them in a different direction. Rather, she permitted and nurtured this discussion (in part, through the above and other redirections), recognizing that weighing the advantages and disadvantages of the two proposed methods could be an informative and rich inquiry experience for her students. She also extended the discussion beyond the single class session, assigning her students to try one or the other (or both) experimental possibilities at home and having them share out the results the following session.

The second example took place on the fourth day of the implementation and occurred as part of this follow up discussion. One student, Larry, shares that he generated both puddle and cup set-ups at home. This prompts Mrs. Miller to ask her students to compare and contrasts Larry's two procedures, to which Henrietta proposes that a puddle provides "more room to evaporate" (see Transcript 5.4d for full text of these comments). Mrs. Miller then invites Larry (via a FC1 CON redirection) to consider and explain Henrietta's claim. In so doing, Larry generates a "layer" model of evaporation, where he suggests that water evaporates from the top down, in a series of layers. Soon after Larry's proposal, Xander attempts to share what he tried at home. Rather than allowing Xander to continue in this vein, Mrs. Miller prevents him from sharing his experiment by issuing a HLD redirection: "Can we hold off on yours for a second, because I want to follow-up on what he's saying? Does anybody else want to comment about this whole idea that evaporation happens in layers?" Thus, she invites her class to return their collective focus to L's layer explanation. Ultimately, Larry's model grounds a theoretical discussion of evaporation for a quarter hour.

In the previous implementations, Mrs. Miller might have allowed Xander to share his comment and, thus, permit the students to shift their attention away from Larry's layer model. What distinguishes this segment, however, is the fact that Mrs. Miller instead stops Xander from doing so. She allows for additional discussion on Larry's interesting and reasonable explanation for evaporation, a topic the other students were ready and willing to continue elaborating. As a result, Larry's concept of evaporation takes on a lengthier lifetime.

The final, and possibly most compelling example of Mrs. Miller's responsiveness from any of the three implementations is what follows a student's assertion that "only water evaporates." This unprompted claim was made late on the fifth day of the module, after the students had already spent forty minutes collectively designing an experiment in which to investigate the rate of evaporation. Mrs. Miller had guided her students through the experimental design process, leading them through a series of minimal redirections (FC1 MIN) in order to "decide" on a protocol. The class ultimately opted to place three cups, each with the same amount of water, in three different locations: outside, inside by the window, inside under a lamp. They were then to monitor the cups over time in order to determine the speed at which the water evaporated. The students, despite responding to Mrs. Miller's prompts throughout the session, seemed rather hesitant participants in the discussion.

The following excerpt follows the students' placement of the three cups in their respective locations and begins with an invitation by Mrs. Miller to make suggestions as to, "Now what?" While this excerpt is a bit lengthy, I include the entire segment for two reasons. First, it includes Adrienne's initial introductory statement that only water evaporates (NOTE: Adrienne later changes "water" to "liquids," although Mrs. Miller ultimately takes up her original statement "Only water can evaporate.") More importantly, however, it includes the dialogue *prior* to Adrienne's statement, which supports a claim that Mrs. Miller originally intended the class to go in a different direction.

Transcript 5.4k [3.5.40:56 - **bold *italics*** typeface indicates redirection]

Mrs. Miller: So, now what? Okay, so now what? Nathan?
Nathan: Maybe now we can, I don't know.
Mrs. Miller: Maybe now we can, I don't know?
Nathan: Maybe (pause) talk or something.
Mrs. Miller: What do you want to talk about?
Nathan: Talk about how [the experiment is] going to happen. Like- What's gonna happen?
Mrs. Miller: Here? (points to the "hypothesis" section of the class chart) (Nathan nods.) So you want to talk about what we would put here? ***So does everybody have to have the same thing here?***
Adrienne: No.
Mrs. Miller: So you're telling me then you can do the same steps but find out different stuff?
Adrienne: Yes.
Mrs. Miller: And what is that other stuff you want to find out?

Adrienne: …If people use these same steps, but they may put it in a larger cup and a little more water. And maybe it's not a clear cup, it's a glass cup. So they could do different, they could do the same basic ideas but just have a larger, other stuff. Like they could use, it also matters if maybe they use salt water, they could use salt water. And they could do it in the direct sun when it's not raining outside and all gloomy. But they could do it when it's hot and humid like we had a few days ago. So they could do different stuff but the same ideas.

Mrs. Miller: So different stuff but basic same ideas. So why is it that you said put salt in it? What is it that you would want to-?

Adrienne: I notice salt, it makes the density of the water a little more, I think that's the word, density, it makes it a little more heavier. So it may, with salt water I don't really know, but my prediction with salt water is, it may make it a little harder to evaporate, because it has. And maybe when you pour it in and then it evaporates, maybe all that's left is the salt. Like we did sort of the same idea in 4th grade, we had salt crystals and vinegar. We put them in a little dish and then we left it out, and when we came back, it had little salt crystals in it. So maybe, and we used salt water also, and when we came back, all the water was gone, and it had only little salt crystals.

Mrs. Miller: So the water was gone, so the water was gone, but the salt was still there? [Adrienne: Yeah.] So what was-?

Adrienne: Because only water can evaporate, because salt is a sold, not a liquid, like water's a liquid, and I think only liquids can evaporate. [Mrs. Miller: Oh.] If you put lemonade out, then that could evaporate, too, because it's just water. And if you had-

Mrs. Miller: But stick with the lemonade, what happened? … First you said saltwater, the salt is left behind to form crystals and only water evaporates. But then you said lemonade- Tell me what happens with the lemonade?

Adrienne: I meant liquids, liquid can evaporate. I don't know for a fact, but I think that it seems if water can, lemonade is also a liquid, and so is iced tea or something. So maybe all the liquids, maybe just not solids. If you had salt in salt water, that couldn't evaporate, because that's a solid, and solids don't evaporate.

Mrs. Miller: ***Is there something solid in lemonade?*** [Students: Ice.] ***What would happen to the ice?***

Prior to this excerpt, the class had nearly filled out a chart consisting of the steps of the traditional scientific method (e.g. question, hypothesis, procedure), leaving the "hypothesis" section blank. Thus, when Nathan initially responds to Mrs. Miller's open-ended query "Now what?" by suggesting that the students could now "talk" about "what's gonna happen" (line 6), Mrs. Miller interprets his suggestion to mean he wanted to fill out the remainder of the class's chart. She then asks the entire class, via a FC1 MIN redirection, whether everyone necessarily needs to write the same steps, to which student Adrienne replies in the negative. She then supports her response by suggesting several different ways that the students could change the initial experimental protocol (e.g. larger cup, more water, salt water). In the exchange between Adrienne and Mrs. Miller that follows, Mrs. Miller shifts from pursuing experimental design questions (e.g. filling out the chart) to pursuing Adrienne's comments. In line 19, for example, Mrs. Miller agrees with Adrienne's suggestion that the students could do "different stuff" but still engage with the "same basic ideas." This acknowledgement is consistent with a focus on completing the experimental design. In lines 28-29, on the other hand, Mrs. Miller requests more information about the evaporation of salt water, a phenomenon raised by Adrienne. Mrs. Miller similarly requests additional information regarding the evaporation of lemonade in lines 33-35, another phenomena raised by Adrienne. Thus, Mrs. Miller's responses to her student during this excerpt seem to mark a transition from pursuing a content objective (experimental design) to pursing a student's idea.

Adrienne ultimately responds to Mrs. Miller's questions by suggesting that only water evaporates (line 30) and later modifying this statement to include all liquids (line 36). These two assertions prompt Mrs. Miller to issue a series of redirections, all of which serve to focus her students' attention on Adrienne's comments, initially with regards to elaborating the evaporation of lemonade (line 40), and shortly thereafter to Adrienne's broader evaporation claims:

Transcript 5.4l [3.5.46:11 - ***bold italics*** typeface indicates redirection]

> **Mrs. Miller**: ***Anybody ever let any other liquids evaporate?*** No, Emma, you didn't, so what are you shaking your head, what do you have your hand up for, you want to say something else?
>
> …[discussion ensues for a few minutes]…
>
> **Mrs. Miller**: … ***Alright, so I want to go back to A says, she said that only water evaporates… So how many of you think that that's true, or not true, or what do you think about that***? With that statement, what do you think, only water evaporates, Ben?

The animated discussion that follows these and other redirections extends beyond the fifth day and ultimately grounds the students' discussion and activity for the next five class sessions. The examination and evaluation of Adrienne's claim that "only water/liquid evaporates" provides the foundation for student generated explanations of evaporation, student motivated experimentation ("Do you want to test that?"), and several student piloted debates. What began as a progression through the "scientific method" to design an experiment transitioned into rich and comprehensive student driven inquiry around a student's idea, mediated in part through Mrs. Miller's redirections.

Conclusions

An analysis of Mrs. Miller's redirections provides evidence to suggest the presence of change in her practice; however, such an analysis, by itself, seems to paint a limited view as to how she changed with respect to her responsiveness. By considering the concept of the lifetime of student's idea and how redirections can extend that lifetime, a more comprehensive picture of change emerges.

Figure 5.3 presents an interpretation of Mrs. Miller's change across implementation, as reflected by the *relative* numbers of her redirections and her missed opportunities. In looking across the three implementations, Mrs. Miller shifted from issuing many redirections in the first implementation, to issuing relatively few in the second, to again issuing many in the third implementation. Close examination of these redirections, however, suggests that despite Mrs. Miller's numerous redirections in implementation one, few of them actually served to extend and nourish the development of her student's potentially productive ideas. There were many instances of missed opportunities where student ideas were missed or dismissed, rather than taken up and elaborated. In contrast, Mrs. Miller's redirections during the second implementation, while fewer in number, more often served to perpetuate the lifetime of student ideas. Hence, there were fewer missed opportunities than during implementation one, despite the fact that there were fewer redirections. In the third implementation, Mrs. Miller again issued a high number of redirections. This time, however, these redirections more often took up and perpetuated the development of student ideas, leaving fewer opportunities missed than in previous implementations. Such a characterization of Mrs. Miller's practice suggests that Mrs. Miller ultimately grew in her responsiveness to her students over the three iterations of the water cycle module.

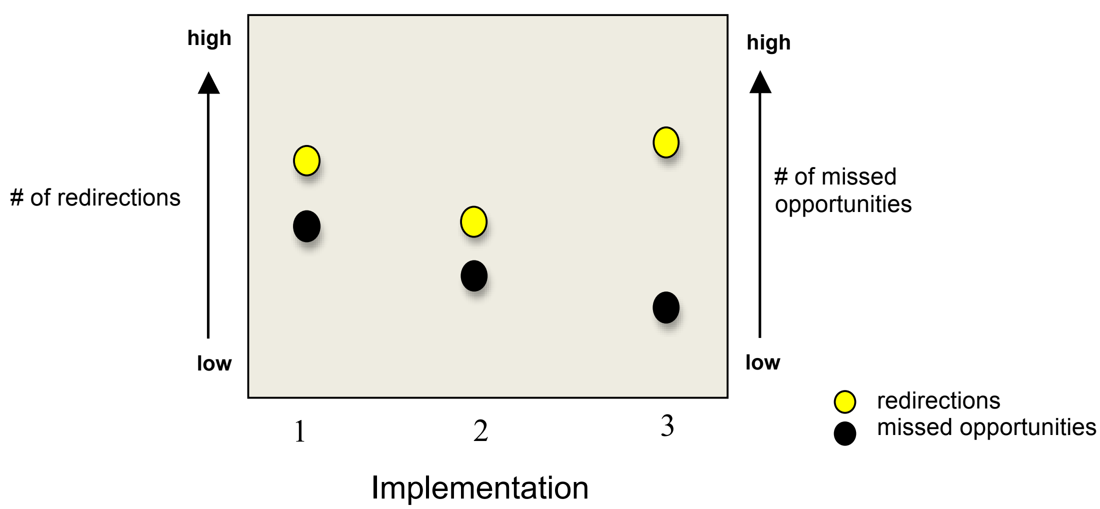

Figure 5.3 *Relative #s of Redirections and Missed Opportunities Across the Three Module Implementations*

The construct of redirection affords a wonderful means by which to quantitatively and qualitatively examine a teacher's practice, specifically with respect to investigating a teacher's responsiveness to her students' ideas. However, it represents only one dimension of a teacher's practice. The following chapter attempts to generate a richer picture of Mrs. Miller's change, by taking a more phenomenological approach when describing her practice.

CHAPTER 6: MRS. MILLER'S PRACTICE ACROSS SIMILAR EVENTS

The previous chapter characterized changes in Mrs. Miller's practice as reflected by her use of different kinds of redirections. While they are arguably useful tools in tracking a teacher's change in responsiveness over time, redirections represent only one aspect of a teacher's instructional practice. Such a narrow focus could restrict the larger story of a teacher's change by excluding other dimensions of practice. In order to generate a more comprehensive view of Mrs. Miller's change in responsiveness, an analysis that includes more of her instructional moves and strategies is required. In chapter six, I present the results of a phenomenological approach to analyzing Mrs. Miller's practice (van Manen, 1990), subjecting a small subset of the classroom data to an inclusive, rather than reductive examination. Such a broad lens affords a means to capture more of Mrs. Miller's evolution in responsiveness.

The first section briefly characterizes two phenomenological "events" ("Day 1" and "Ice Bag") that occurred in each of the three module implementations. Section 6.1 also presents a justification as to why these two events represent appropriate means for contrasting Mrs. Miller's practice across implementations. Sections 6.2 and 6.3 contain descriptions and analyses of Mrs. Miller's practice during the "Day 1" event, while sections 6.4 and 6.5 consist of descriptions and analyses of Mrs. Miller's practice during the "Ice Bag" event. The final section, 6.6, synthesizes the findings from the previous sections.

6.1 An overview of the two selected events: "Day 1" and "Ice Bag"

Despite the fact that there was no particular sequence of topics to be covered in the LP water cycle module, there were several similar questions and concepts that emerged during the three implementations. Such topics can be viewed as recurrent "events" from which one can explore and compare Mrs. Miller's instructional moves and strategies across time. If Mrs. Miller employed specific strategies when the topic was addressed in the first implementation and different strategies when it was revisited during the second and third implementations, for example, it might be possible to make claims about how Mrs. Miller changed in her practice. The first step in this type of analysis is, therefore, to select one or more of these events as contexts for comparison. Since Mrs. Miller might employ different instructional moves and/or strategies when engaging her students in discussion about different topics, I felt it necessary to choose more than one event. Ultimately, I selected two events for further analysis: Day 1 and Ice Bag, each of which are described below.

The first event, "Day 1," was the initial class session of each of the three implementations. There were two reasons for selecting the first session as one of the two events for analysis. First, Mrs. Miller elected to begin each of the three implementations with a similar "disappearing puddle" launching question. Secondly, the Day 1 event was restricted to *only* the first class session, which was similar in duration for each of the three implementations (between 45 - 60 minutes). Thus, this event was similar in terms of its *introduction* (the puddle question) and *time interval* (one class session), thus providing a reasonable context in which to compare Mrs. Miller's practice across time.

The second event chosen was that of the collection of discussions and activities that concerned the formation of liquid water on a plastic bag of ice. Unlike Day 1, the so-called "Ice Bag" event was identified by virtue of the *focus* of the class's discussion/activity, rather than its occupancy of a specific interval of class time. Although the manner in which the event developed and was discussed differed among implementations, Ice Bag emerged and was sustained as the center of the class's attention at some point during each of Mrs. Miller's three module implementations.

There were several reasons for selecting Ice Bag as the second of the two events for comparing Mrs. Miller's practice across implementations. First, the scientific process underlying the phenomenon (e.g. condensation of water vapor on a cold surface) is a content element often included within traditional science curricula involving the water cycle (e.g. FOSS curricula, Lawrence Hall of Science, 2007) and is typically listed in state elementary science standards (e.g. California Department of Education, 2000). This concept can also be challenging for students (Southerland, Kitleson, Settlage, & Lanier, 2005). Thus, it might be illuminating to examine and compare Mrs. Miller's moves while working with her students in this particular content area. Second, Ice Bag did not begin with a specific question or launching point, nor was it confined to a single class session, unlike the Day 1 event. As such, it was possible that Mrs. Miller might use different types of instructional moves and strategies when engaging her students under the less structured and more fluid conditions. Finally, the discussions and activities concerning the "ice bag" phenomenon did not emerge until late in all three implementations (Day 11 or later). Thus, this event had the potential for highlighting instructional practices that Mrs. Miller might have evolved over the course of the module implementation. In short, Ice Bag offered a nice contrasting context with which to compare Mrs. Miller's practice on Day 1.

Once the two events were chosen, the relevant classroom data (e.g. video recordings and transcripts of the recurring "events") were closely examined for changes in Mrs. Miller's practice. In particular, Mrs. Miller's questioning strategies, redirection usage, and responses to her students were noted and evaluated for how they reflected her responsiveness to her students. Audio recordings and field notes of the debriefing sessions provided additional data to support findings of change.

6.2 Descriptions of the "Day 1" events

This section consists of brief descriptions of Day 1 for each of Mrs. Miller's three implementations of the water cycle module. In each case, the class session could be divided into two segments: (1) the "initial puddle discussion," or IPD, where the students considered the disappearing puddle, and (2) the "end game discussion," or EGD, where the students reconsidered previous comments and attempted to generate consensus regarding the phenomenon. Table 6.1 provides a synopsis of Day 1 along several parameters, including approximate length of the IPDs and EGDs. In the subsections below, I provide an overview of the IPDs and the EGDs for each implementation.

Table 6.1 *General breakdown of the "Day 1" events across implementations*

	Implementation 1	Implementation 2	Implementation 3
Phrasing of IPD	*"What happened to the rainwater?"*	*"What happened to the rainwater?"*	*"What could have happened to the puddle?"*
Individual reflection time	None	30 seconds	3 minutes
Length of IPD	40 minutes	40 minutes	40 minutes
Phrasing of EGD	*"Let's go back…and answer the question."*	*"What are some things…that we can agree to?"*	*"What…do we need to add…to be able to answer this [puddle] question?"*
Length of EGD	10 minutes	15 minutes	15 minutes

Note. IPD (initial puddle discussion) = the collection of conversations grounded in the disappearing puddle question. EGD (end game discussion) = the final discussion held at the end of class. All times are approximate.

Implementation 1: Day 1

Initial Puddle Discussion:

Mrs. Miller launched the first module by posting the initial puddle question on the front board. The question was phrased as follows:

> "Suppose that one night it rains. When you arrived at school you notice that there are puddles of rainwater in the parking lot. But when you go home you notice that the puddles are gone. What happened to the rainwater?"

After revealing the written question, Mrs. Miller paraphrased the question verbally and allowed her students to respond. Several students immediately volunteered answers, while others opted instead to write or draw their thoughts on individual white boards. All of the responses shared aloud either incorporated the term "evaporation" or mentioned the formation of "water vapor." Mrs. Miller then took up the term "evaporation" and asked if her students knew what it meant. Although a few students did attempt to explain the term, little discussion followed their comments. Mrs. Miller then asked her students if they were all "talked out."

Eventually, after a few lengthy pauses, the students began to express more and more of their thoughts and ideas about evaporation. Several issues concerning evaporation were raised, including: the potential role of the sun in evaporation, whether evaporation could happen from deep lakes and/or rivers, and what might happen to the Earth without the sun. During this segment of class, Mrs. Miller's students posed a number of thoughtful questions and explanations, many of which were not pursued by other members of the class. One student, for example, proposed that running water shouldn't evaporate as quickly as still water, and another queried whether soda and/or wine were capable of evaporating. At only one point in the session did a student raise the possibility that something *other* than evaporation could have caused the puddle to disappear (i.e. Jack asked, "What would happen if someone stepped on it? Like…stepped on the water?" [1.1.33:01). Mrs. Miller, however, quickly dismissed this possibility as a non-factor, and the conversation shifted in a different direction.

<u>End Game Discussion:</u>

Forty minutes into the class session, Mrs. Miller drew the "initial" discussion to a close and invited the students to revisit the puddle question.

Transcript 6.2a [1.1.39:37 – italics indicates speaker's emphasis]

MM: This looks like a good point to- (goes to front easel) Think about some things. (Flips sheet) First of all, you want to- go back and record some of things that we said…Some of you did a water cycle. Some of you had your own thoughts. But, for those of you that don't have your own thoughts, let's kind of- Give us something to write down here. So, there's the question (points to the original question). So, let's go BACK and discuss …Let's go back to and answer the question. So that we can ALL have something in our journals today. Right? So, if you've already *got* what

> you think is the answer to this question? Here. (points) You can *write* the question first. And you can summarize this part here. Just- Say: "It *rained*. And there's *puddles*. And then- later in the day the puddles are gone." You can summarize … For those of you that aren't sure what to write, let's go ahead and put some answers up here.

Mrs. Miller's students proceeded to repeat and elaborate earlier comments about evaporation and the generation of water vapor, many of which were ultimately inscribed on the front board by Mrs. Miller. As the puddle discussion began to wind down, a number of students posed new questions concerning water-related topics. One student asked, "What are clouds made of and how do they float?" Another questioned, "How can the fog hold the water?" When several individuals indicated they'd like to respond to these and other questions, Mrs. Miller ended the conversation and had her students write down their thoughts in their journals.

Implementation 2: Day 1

Initial Puddle Discussion:

Mrs. Miller launched the second module implementation by posting the identical puddle question as that which had been posted in Implementation 1:

> "Suppose that one night it rains. When you arrived at school you notice that there are puddles of rainwater in the parking lot. But when you go home you notice that the puddles are gone. What happened to the rainwater?"

Mrs. Miller then paraphrased the question for her students verbally and gave her students time to "think about" the question and "jot some thoughts" down in their journals. After about thirty seconds of individual reflection, she asked her students to share their ideas with the rest of the class. Several students proceeded to offer their thoughts, all of which Mrs. Miller recorded in a notebook. The students' responses included that the puddle:

evaporated, seeped into the ground, went into the sewer/storm drain, and had been kicked.

Once a number of explanations were posited, Mrs. Miller took up the term "evaporated" and asked her students to tell her what it meant, since "she is not really sure [she] understands" it. After a few students elaborated the term, Mrs. Miller revisited another student's comment about the puddle "seeping" into the ground. The student's response to this follow up question provided the foundation for a lengthy discussion that touched upon a variety of topics, including: the physical components of parking lots, the role of humidity in evaporation, students' previous experimentation experiences with evaporation, and the role of the sun in evaporation. At one point during this segment, a student observed that he'd noticed water appearing on desert cactus in the early morning. He considered "fog" to be the reason behind this appearance. Although Mrs. Miller went on to push for additional comments and/or explanations for this water formation, alternatives were not forthcoming. The conversation meandered to different subjects, with Mrs. Miller often requesting her students make connections between comments. Eventually, Mrs. Miller returned to the idea of "evaporation" and asked whether her students could now better explain it. Several of the students then proceeded to elaborate earlier statements.

<u>End Game Discussion:</u>

After forty minutes of discussion, Mrs. Miller requested that her students take a few minutes to review previous conversation topics with a neighbor. She also asked them to generate a list of what they could "agree upon" and which thoughts/ideas they thought should be "put aside."

Transcript 6.2b [2.1.39:01 – italics indicates speaker's emphasis]

MM: Alright. We *said* quite a few things. Quite a few people shared. We said *quite* a few things. Perhaps now we need to- Clarify within ourselves what we can agree to, in- Remember our- opening question (gestures toward the sheet on the board). What are some things that we've said that we can *agree* to? As a class? And somethings we're not sure about. So, if you could just- Turn and talk to your table partner about *what* we've discussed. What seems to keep coming up, that we can kinda agree to? And maybe *clarify* that. And maybe some things we can kinda- put off to the side, 'cause we're not sure about. Go ahead. [Students begin to talk with their neighbors.]

Once the students had engaged in small group talk, Mrs. Miller had them share out their thoughts. Individuals offered several possibilities upon which they thought the class could agree, including the terms: "evaporation," "condensation," "precipitation," the fact that heat/sun played a role in evaporation, and the possible role of a "cycle." The session concluded with a student sharing "five easy steps" to evaporation, and Mrs. Miller's subsequent request for the students to record additional interpretations and/or explanations for the puddle phenomenon in their journals.

Implementation 3: Day 1

<u>Initial Puddle Discussion:</u>

Mrs. Miller launched the module by posting a slightly modified puddle question than had been posted previously. The question was phrased as follows:

> "One night it rains. When you get to school the next day you notice a large puddle of water on the driveway. Later that day when leaving school you notice that the puddle is gone. What could have happened to the puddle?"

Once posted, Mrs. Miller read the question aloud and allowed approximately three and a half minutes for her students to individually record “situations that could explain what happened to the puddle.” After a few minutes of silent reflection, Mrs. Miller asked for volunteers to share ideas with the rest of the class. Several students offered their thoughts, all of which Mrs. Miller noted in her notebook. These explanations included that the puddle: evaporated, had been run over by a car, was drunk by someone or something (i.e. animals), went into the sewers/storm drain, and had been jumped in by students.

Once a variety of explanations were posited, Mrs. Miller acknowledged that she’d heard the terms “evaporation,” “evaporate,” and “vaporize” several times and wondered if someone could “explain what that meant.” A few students then volunteered explanations, all of which involved the sun. Mrs. Miller responded by asking the class “what the sun ha[d] to do with this.” Several students went on to make suggestions, after which Mrs. Miller allowed her students to pose additional alternatives for what may have happened to the puddle. The students engaged in a lively and animated discussion, with several unusual explanations raised for consideration (i.e. a backpack soaked up the water, a gardener mopped up the puddle). During this time, Mrs. Miller rarely participated in the conversation other then to interject brief acknowledgements or to call on a student. At one point, the conversation entered a particularly “silly” phase, to which Mrs. Miller suggested that the students might want to consider more “reasonable” explanations for where the puddle could have gone.

End Game Discussion:

After forty-five minutes of dynamic discussion, Mrs. Miller read some of her notes aloud and stated that, based on the students' comments, her general feeling was that it is impossible to definitively account for where the puddle had gone. She invited her students to talk with their neighbors and generate a list of what *additional information* might be necessary in order for the question to be properly answered.

Transcript 6.2c [3.1.44:21]

MM: Let's back up a little bit, let's go back to the original question…So what I'm hearing from all the things that you're saying is. You started off. I'm going to go back to look at my notes. You started off by saying water kind of floats, has something to do with evaporation. That there's a time element involved. That how much rain, how big was the puddle. That there's more heat on the edges of the puddle. That we don't know how much time really has elapsed. So I'm thinking that, as I think about all those questions you guys came up with. What's coming to mind is, we don't have enough information. So what I would like you guys to do is, turn to the next blank page. And using this (points to the initial puddle question), what information do we need to add to this, to be able to answer this question? Or you might say, what information is missing that we need to add? So you might think of it in both of those terms. Look at this question, what needs to be added to this to help us answer this question? So you're going to write, write this out….A sentence, you can use bullets, you might have 5 ideas, someone might have 5 things that are missing. That we can't really answer this question yet because of what you guys already mentioned. Because Henrietta mentioned- Smaller puddles. And then something about the size, we don't know how big it is, we don't know how long it was. Does that make sense? Okay, so let's refocus and come up with some things we need to know to be able to better answer this question. Of course, you may always draw pictures, if drawing a picture helps you... And talking to your neighbor right now might be a good thing, too. This might be a good time to discuss with your neighbor what you're thinking.

After a few minutes of small group talk, the students shared their ideas with the class. Mrs. Miller listed several of the students' suggestions on the front easel, some of which consisted of noting: the weather, the size of the puddle, the timing of the observations, the exact location of the puddle, whether the puddle was in the sun or shade, and the slope of the driveway. Mrs. Miller concluded the session by asking her students to consider the puddle scenario further for homework.

6.3 Analysis of "Day 1" events

A comparison of Mrs. Miller's practice across Day 1 events reveals several similarities and differences in how Mrs. Miller engaged with her students. The subsections that follow present these results in detail. The final subsection summarizes the findings and describes how they support a claim that Mrs. Miller changed with respect to how she responded to her students' thinking over time.

Similarities

There are several similarities to be found in Mrs. Miller's practice across the three Day 1 events. First, Mrs. Miller structured the events similarly, introducing the sessions with a launching puddle question and concluding them with a review of previous comments. The initial puddle discussions (IPDs) generally lasted for forty to forty-five minutes and consisted of all the questions and topics that emerged as a result of the launching puddle question. The end game discussions (EGDs) generally lasted from ten to fifteen minutes and centered on generating consensus concerning a particular issue related to the initial puddle question. Each EGD resulted in the creation of a list that highlighted some of the class's findings.

A second similarity across events was that Mrs. Miller consistently made room for students to express their ideas, thoughts, observations, and explanations during discussion, particularly during the IPDs. Mrs. Miller began each of the Day 1 sessions by posing an initial, open-ended puddle question and inviting many students to offer explanations. She also issued additional open-ended questions at several points during the three IPDs, each of which made space for students to volunteer further ideas and observations. In point of fact, Mrs. Miller only spoke for approximately 30% of class time in each of the three Day 1 IPDs, with the remainder of the time being occupied by students sharing their thoughts, observations, and experiences.

Third, Mrs. Miller tended to take steps to encourage her students to listen to and elaborate each other's comments as ideas emerged over the course of discussion. To illustrate this point, consider Mrs. Miller's talk turns in the following two segments of transcript. The first piece is taken from the IPD of Implementation 1. The second piece is taken from the IPD of Implementation 3.

Transcript 6.3a [1.1.16:28]

Tommy: I think that the only reason that the puddles even went up was- The sun? That's our biggest source of heat? And, it usually- If you have a big puddle like that? It wouldn't affect- affect like a lake? Or something? But, it- little ponds like that? It would actually- Well, now that I'm thinking about it- Maybe it's because it has shallower water to heat up and so, lakes don't- I don't know…

Mrs. Miller: Britta? What do you think about Tommy's comment that only- OK. Maybe, I'm not correct on what- Tommy said that only water in- like in a puddle- not like a big lake, evaporates. Is that what you said?

Tommy: Shallow. Like shallow waters.

Mrs. Miller: So, you're saying only shallow water evaporates. What do you think about that Britta?

Britta: …Like water's like that? I don't think that- like, when it evaporates? It won't take as much water? So, they just take the little puddle of water instead of taking like a lot of water from the- ocean or something like that.

Transcript 6.3b [3.1.16:54]

Henrietta: The water kind of floats, but it takes, if you went to school, that probably took about 7 or 8 hours. So then when he got back, the water gets into little probably microscopic little sections, and then it floats up, kind of floats up. People can't see it, but if you leave a cup out for the night or for the day, it will probably evaporate. And the water will, it won't, you can't see it, so it can't go in drops. But it can go in little sections, little pieces at a time, or maybe all at one time go up.

Mrs. Miller: Adrienne, you want to respond to that?

Adrienne: I think Henrietta, she had a good theory that, you never know, he could have, some people have longer school days…

In both transcript segments, Mrs. Miller invites a student to build on or develop another student's comment. In Transcript 6.3a, Mrs. Miller asks Britta what she thinks of Tommy's comment that only shallow water evaporates (line 8). In Transcript 6.3b, Mrs. Miller asks Adrienne if she'd like to respond to Henrietta's comment that evaporation happens in "microscopic little sections and…floats up" (line 6). These types of facilitation moves were common during each of the Day 1 IPDs and served to encourage students to listen to and elaborate each other's ideas.

Finally, there were common content areas that Mrs. Miller highlighted in each of the three Day 1 events. Specifically, Mrs. Miller invited her students to explain the process of evaporation and elaborate the sun's role in evaporation at some point in each of the three IPDs.

Differences

The differences in Mrs. Miller's practice across Day 1 events can be grouped into three distinct categories. The first category, "Launch" differences, consists of the collection of differences relating to how Mrs. Miller initiated the puddle discussion (IPD). The second category, "Facilitation" differences, includes the differences that concern how Mrs. Miller facilitated her students' interactions and exchanges during the ensuing discussions. The final category, "Conclusion" differences, concerns how Mrs. Miller brought the Day 1 sessions to a close. The following paragraphs characterize these differences more fully.

<u>Launch differences</u>:

As described in the previous subsection, Mrs. Miller began each Day 1 session with an initial question concerning what happened to a puddle of rainwater. A comparison of the Day 1 events reveals two primary differences in how Mrs. Miller approached "launching" this initial discussion with her students. The first difference concerns the subtle change to the phrasing of the puddle question for Implementation 3. Although the content of the question is arguably the same for all three implementations (i.e. a puddle of rainwater disappears over the course of a school day), the two different ways in which the question was worded (Implementations 1 and 2 v Implementation 3) seem to reflect slightly different stances on the phenomenon. For example, the final question for the first two implementations, "What *happened* to the puddle?" suggests that there is a definitive answer to the question. Possibly because of this launch, the students only proposed explanations that related to the process of evaporation on Day 1 of the first implementation. The fact that Mrs. Miller later dismissed the only "non-evaporation" possibility raised by a student reinforces this "only-one-explanation" perspective.

In contrast, the phrasing of the final portion of the scenario in the third implementation read, "What *could* have happened to the puddle?" The word "could" seems to connote that there is the potential for more than one explanation for where the puddle went. Given this opening, it is unsurprising that the highest number and most diverse list of possible explanations was generated on Day 1 of Implementation 3.

The second launching difference relates to how Mrs. Miller *verbally* posed the question to her students. On Day 1 of Implementation 1, Mrs. Miller turned to her students, asked, "So. What happened to the rainwater?" and immediately invited her students to respond. The specific phrasing of this question (e.g. "What *happened…*"), similar to that of the written question, reinforces the underlying message that there is only *one* answer to the question. Thus, it is unsurprising that the students' responses all include the term, "evaporation."

While the phrasing of the initial puddle question remained the same for Implementation 2, the manner in which Mrs. Miller verbally introduced the question to her students was altered. In contrast to how she handled the first Day 1 session, Mrs. Miller prevented her students from answering the question immediately and invited them to first reflect on the question individually. Specifically, she asked them to "jot down a couple ideas" and to record their thoughts. This launch differed from that of Implementation 1 in two important ways. First, Mrs. Miller provided her students with *time* to collect their own thoughts. Secondly, while subtle, the fact that she used the terms "ideas" and "thoughts" (plural) seems to imply that her students *could* have more than one idea or thought as to what happened to the puddle. Thus, it is not surprising that this time the students offered a variety of explanations as to where the puddle went.

The launch of the third IPD extended the launching question modifications even further. As mentioned previously, the phasing of the written question for Day 1 of Implementation 3 ("What *could have happened* to the puddle?") seems to suggest that there could be more than one explanation for the disappearance of the puddle. Mrs. Miller confirms this intimation with her verbal request that her students take several minutes to reflect on the question individually and write "down ways…situations that could explain what happened to the puddle." Her invitation for her students to list "ways" or "situations" (plural) seems to reaffirm that there are several potential explanations worthy of consideration. The fact that Mrs. Miller then provided her students with extended time to think quietly (i.e. several minutes) *prior* to sharing out afforded them a sufficient interval to consider, and list, such alternatives.

<u>Facilitation differences:</u>

Once the IPD was underway, Mrs. Miller employed several different instructional moves to mediate and perpetuate her students' conversation. These included: calling on additional students to respond, acknowledging and/or rephrasing students' comments, asking follow up clarification and/or elaboration questions, issuing redirections, and inviting students to elaborate or critique each other's comments. While none of these moves were necessarily unique to specific implementations, the *types* and *frequencies* at which these facilitation moves were employed differ across the IPDs of the three implementations.

Table 6.2 displays the breakdown of different types of focus redirections and follow-up probes issued by Mrs. Miller during each of the Day 1 events. Recall from chapters 4 and 5 that focus redirections are bids to shift the focus of the students' collective attention during discussion. There are several different types of focus redirections, including several in-the-moment redirections (i.e. FC1 redirections), more example redirections (MEX), hold-off redirections (HLD), delayed focus redirections (FC2), and non-responsive redirections (FC3). Each of these redirections reflects a specific type of responsiveness on the part of Mrs. Miller towards her students.

Table 6.2 *Day 1 Across Implementations: Mrs. Miller's Redirections and Follow up Questions*

	Implementation 1	Implementation 2	Implementation 3
Redirections (total)	**11**	**21**	**9**
FC1 TRM	1	2	1
FC1 MIN	1	1	1
FC1 MOR	2	1	1
FC1 CON	2	4	4
MEX	0	6	1
HLD	0	1	0
FC2	5	6	1
FC3	0	0	0
Follow up Qs (total)	**39**	**39**	**27**
General	7	5	4
Specific	20	20	12
Leading	5	3	3
Revoicing	7	8	6
Other	0	3	2

Note. FC1 TRM = Focus redirection around a specific term or phrase, FC1 MIN = Focus redirection minimally connect to student comment, FC1 MOR = Focus redirection inviting elaboration of student comment, FC1 CON = Focus redirection inviting consideration/reasoning about student comment, MEX = More examples redirection, HLD = Hold off redirection, FC2 = Delayed redirection, FC3 = Redirection not associated with student comments.

Follow-up probes are Mrs. Miller's questions or statements that encourage individual students to extend their thinking. In their work analyzing teacher discourse, Franke and her colleagues (2009) classified such questions into four different categories. For the Day 1 analyses, I elected to adopt Franke et al.'s classification scheme and add a fifth category, as seemed warranted by the data. *General* probes included non-specific invitations for a student to make a further comment and include questions such questions as, "Can you say more?" or "What do you mean by that?" *Specific* probes, in contrast, consisted of questions that took up specific aspects of a student's comments and requested clarification and/or elaboration (e.g. "To heat up. Then what happened?" or "How was that different than … fog?") *Leading* questions were probes that guided students toward a specific response or resolution, such as: "It didn't take the salt or sugar, right?" and "But, it *did* eventually evaporate?" Although not a category used in the Franke et al (2009) study, Mrs. Miller's also utilized *revoicing* probes as a means to invite students to extend their thinking. Revoicing probes consisted of questions or statements in which Mrs. Miller rephrased a student's comment in such a way as to clearly request clarification and/or elaboration. For example, when responding to a student's comment that he wasn't able to use his boat because of the low water level, Mrs. Miller asked, "When you went out to the dock…to use your boat, you couldn't get to your boat?" Her rising intonation at the end of this revoiced talk turn clearly invited the student to elaborate the situation. Finally, there was an *Other* category, which included any follow-up question or statement that didn't necessarily fit any of the previously mentioned categories (Franke et al., 2009).

When follow up probes and redirections are compared across implementations, a few interesting findings emerge. First, Mrs. Miller issued the *most* focus redirections on Day 1 of the second implementation and the *fewest* on Day 1 of the third implementation. These results are particularly interesting, given that the second implementation had the fewest focus redirections overall and third implementation had the most (see Section 5.3). While it is beyond the scope of this dissertation to definitively account for such findings, it is reasonable to speculate why this alteration in Mrs. Miller's redirection practice occurred. Day 1 of the first implementation was the very first time Mrs. Miller engaged with her students in this type of open-formatted discussion within the module context. Therefore, the experience may have been overwhelming for her and potentially limited her ability to listen to, process, and move to shift her students' attention in the moment.

On Day 1 of the second implementation, Mrs. Miller had already participated in a complete implementation and, thus, had acquired some experience in engaging students in the open-flexible format of the module. Hence, it may be that she was more comfortable working with student ideas as they emerged. The high numbers of Mrs. Miller's MEX and FC2 redirections during the second Day 1 served to repeatedly redirect the students *back* to the initial puddle question and, thus, draw out additional explanations for what might have happened to the puddle. This behavior reaffirms the earlier suggestion that Mrs. Miller was much more open to considering alternative puddle explanations in the second implementation. Finally, Mrs. Miller commented that her focus for Day 1 of Implementation 3 was to simply "listen" to what her students "had to say" [3.1 – DBRF 08:07]. Given this explicit goal, it is unsurprising that she issued fewer redirections on Day 1 of the third implementation when compared to Implementations 1 and 2.

A second noteworthy difference in how Mrs. Miller facilitated discussions across Day 1 events was that Mrs. Miller issued more follow up probes to her students during Implementations 1 and 2 than in Implementation 3. In particular, Mrs. Miller asked far fewer *specific* follow-up questions on Day 1 of the third implementation than she did on Day 1 of Implementations 1 and 2. Mrs. Miller's comments during the IPD of Day 1 of

Implementation 3 tended instead to consist of revoiced statements *without* rising intonations (e.g. "So, they play with the ball and they slip in the puddle.") or simple acknowledgements (e.g. "OK."). Such statements served to note students' contributions without necessarily inviting clarification or elaboration.

On first pass, this difference in Mrs. Miller's talk might seem somewhat surprising. One might have expected Mrs. Miller to issue an increased number of specific follow up questions in the third Day 1 event, since such a move could be considered an increase in responsiveness. Recall, however, that Mrs. Miller had expressed a strong desire to "listen" to her students during the first class session of Implementation 3 (3.1.DBRF). Hence, Mrs. Miller may have made a concerted effort to resist shaping her class's discussion by limiting her follow-up probes and redirections. While she may have remained less "active" in mediating the conversation during Day 1 of Implementation 3, this tendency was not pervasive across the entire implementation. Indeed, Mrs. Miller's willingness to enter into the discussion did not remain low throughout the third implementation, as evident by the elevated frequency of redirections in comparison to the other two implementations (see Sections 5.3 and 5.4). Since her stated goal for Day 1 was simply to listen to her students' ideas surrounding the disappearing puddle, a focus from which her students never really strayed, perhaps Mrs. Miller was more willing to probe her students' ideas and shift the course of conversation *after* that initial session.

Conclusion differences:

The final category of differences relates to how Mrs. Miller brought the Day 1 discussions to a close. First, Mrs. Miller's approach to the "end game discussion" differed among the three Day 1 events. Although she charged her students to reach consensus with respect to an issue relating to the disappearing puddle on each occasion, the *focus* of that consensus differed. Consider Mrs. Miller's end game "invitations" and the resulting "lists" for Day 1 for each of the three implementations.

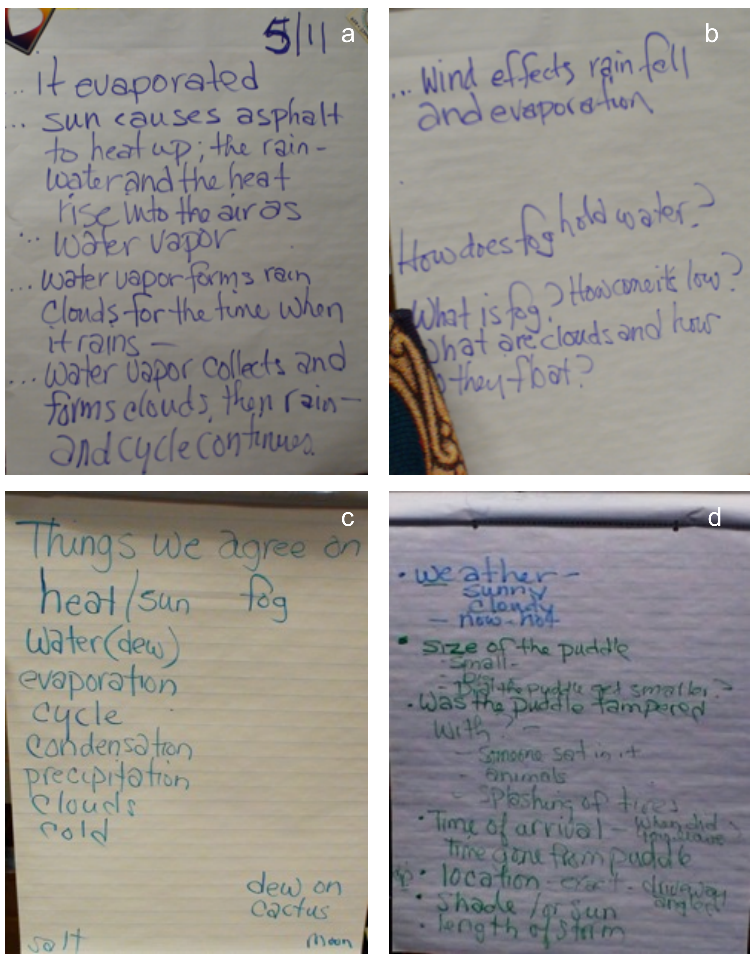

Figure 6.1 *"End Game Discussion" Lists Generated By Mrs. Miller at the Conclusion of the Day 1 Sessions.* (a) Part I and (b) Part II of the "*Answers to the question*" for Implementation 1, (c) "*Things we agree on*" for Implementation 2, and (d) "*What more information do we need*" for Implementation 3.

- Day 1, Implementation 1: After forty minutes of initial discussion during implementation one, Mrs. Miller asked her students to “go back to and answer the question” (Transcript 6.2a, line 5). She then guided them through ten minutes of listing student comments that served to elaborate the process of evaporation (see Figure 6.1a & 6.1b).

- Day 1, Implementation 2, Mrs. Miller invited her students to consider “some things [concerning the opening question] that we’ve said that we can agree to” (Transcript 6.2b, line 3). After allowing a few minutes for the students to discuss ideas with their neighbors, Mrs. Miller facilitated a ten-minute discussion that resulted in a list of these “agreed upon” items (see Figure 6.1c).
- Day 1, Implementation 3, Mrs. Miller invited her students to generate a list of “what information do we need to add to [the initial puddle question] to be able to answer [it]” (Transcript 6.2c, lines 7-8). After allowing a few minutes for the students to reflect individually and/or discuss their ideas with neighbors, Mrs. Miller facilitated a ten-minute discussion that results in a list of such “missing information” (see Figure 6.1d).

Each Day 1 EGD began with an invitation for Mrs. Miller’s students to reconsider previous comments in order to generate consensus. The specific consensus that Mrs. Miller sought, however, differed across the implementations. Mrs. Miller’s end game invitation in the first implementation, for example, can be viewed as an attempt to bring *closure* to the puddle question itself. Her charge to *answer the question* suggests a focus on resolving the opening question and bringing discussion about that puddle to an end. In contrast, the end game invitations on Day 1 of Implementations 2 and 3 suggest that, rather than necessarily *resolving* the initial question, she'd wanted to establish a benchmark as to where her students were in their consideration of the disappearing puddle. Mrs. Miller end game request for Implementation 2 asked students to generate a list of terms and phrases related to the disappearing puddle upon which they, as a class, could agree. Similarly, her endgame request for Implementation 3 asked students to generate a list of information critical to answering the initial puddle question itself. By having the students construct such a stepping-stones, Mrs. Miller affords her students a sense of accomplishment ("We've gotten somewhere!") and provides herself with an opportunity to identify a potential starting point for later discussion/activity.

Interestingly, Mrs. Miller listed several specific student comments prior to issuing the EGD invitation in Implementation 3, "You started off by saying water kind of floats, has something to do with evaporation. That there's a time element involved…how much rain, how big was the puddle. That there's more heat on the edges of the puddle. That we don't know how much time really has elapsed" (Transcript 6.2c, lines 2-5). These comments seemed to inform her ultimate decision to have them supply the missing puddle information: "So I'm thinking that, *as I think about all those questions you guys came up with*. What's coming to mind is, we don't have enough information. So … what information do we need to add to this [initial question], to be able to answer this question?" (Transcript 6.2c, lines 5-8, *italics* my own). Thus, Mrs. Miller's EGD challenge seemed to respond to the specific nature of the students' IPD comments on this final Day 1, more so than either of the two earlier Day 1 events.

The second difference with respect to how Mrs. Miller handled the conclusion of the Day 1 events concerns how Mrs. Miller actually *terminated* the Day 1 discussions. Mrs. Miller seemed to seek closure at the end of Day 1, Implementation 1. By pushing for an "answer" to the puddle question, it appears as if she was attempting to effectively end the puddle topic so as to move on to a different topic on the following class session. Although Mrs. Miller opens Day 2 by asking whether her students had anything more to add to the previous discussion, she halts the conversation 5 minutes later, in order to pursue a completely different topic. Hence, the discussions of the first session of Implementation 1 seemed to stand apart from other discussions during the implementation.

In contrast, the latter two Day 1 conversations were not held as distinct from those in later sessions. Day 2 of Implementation 2, for example, began with Mrs. Miller inviting the students to share any additional thoughts about the initial puddle question. The students immediately launch into an animated discussion that extends outward from the puddle and evaporation. Mrs. Miller perpetuates the discussion and allows emergent topics to drive the direction of the class. Due to the fluid nature of this Day 2 discussion, it is unclear where the puddle question ends and the next topic for consideration begins.

Mrs. Miller similarly began Day 2 of Implementation 3, inviting her students to share additional "puddle" thoughts. After the students volunteer ideas, most of which deal with additional information necessary to answer the puddle question, Mrs. Miller has the students rewrite the initial puddle question in their journal. The students share out their ideas and continue to address issues related to the initial puddle question through the beginning of Day 3. Thus, while Mrs. Miller's concluding choices on the first Day 1 seemed to confine the topics and ideas associated with the opening puddle question to the first class session, her moves on the two subsequent Day 1 sessions allow for the question to bleed into subsequent sessions and provide the foundation on which to build additional discussion.

Summary and synthesis: Day 1 events

Mrs. Miller exhibited several instructional practices that were consistent across the three Day 1 events. She structured the class sessions similarly (e.g. IPD vs. EPD), she consistently elicited student ideas, she encouraged her students to consider and develop each other's ideas, and, at some point during the discussions, she focused her students' attention on evaporation and the sun's role in that process. Mrs. Miller's actions also differed noticeably across events. Her phrasing of the initial puddle question, for example, seemed to reflect an increasing openness and flexibility in terms of encouraging more than one explanation for the disappearing puddle. Her methods of facilitating her students' discussion seemed to suggest changes in her willingness and ability to listen to and display her students' ideas. Finally, Mrs. Miller seemed to differ with respect to how she approached the end game discussions.

Synthesizing the findings from the Day 1 analyses, I contend that there are two overarching claims regarding change in Mrs. Miller's practice across implementations. First, while Mrs. Miller encouraged her students to share their thoughts in all three events, her openness to having her students entertain, communicate, and elaborate explanations that were counter to the "scientifically accepted" explanation of evaporation seemed to increase over time. Her subtle alterations of her written and verbal phrasing of the initial puddle question (e.g. What *happened*... vs. What *could have happened* …) support such a claim. The decrease in the frequency of follow up probes and redirections, in combination with Mrs. Miller's comments during debriefing sessions, provide further support that she wanted to "listen" to what her students had to say about the topic in the third event, rather than direct or shape their thinking in a specific way.

Second, the changes in Mrs. Miller's approach to the end game discussions seems to show a greater level of responsiveness to her students' comments over time. Mrs. Miller stopped her students' discussion on Day 1, Implementation 1 in order to have her students record the "answer" the puddle question. The discussions and activities that followed on Day 2 only distantly connected to the puddle conversations on Day 1 (e.g. the links between cloud appearance, altitude, and weather). In contrast, Mrs. Miller posited to her students on Day 1, Implementation 3 that it didn't seem possible to answer the question, given what she had heard in their comments. The EGD that followed ultimately provided the foundation for the discussions for the next two class sessions. This shift from having her students list "answers" to the puddle question on Day 1 of Implementation 1 to acknowledging that it seemed as if the phrasing of the question lacked sufficient information for it to be "answerable" (as it currently stood) at the end of Day 1 of Implementation 3, I believe, is noteworthy. Indeed, it indicates a change in Mrs. Miller's practice towards a greater tendency to allow her students' comments to inform the direction of the end game discussion *and* ground discussions for future sessions. Such a change supports a claim of increased "in the moment" and planned responsiveness (see Section 5.4) on the part of Mrs. Miller.

6.4 Description of the "Ice Bag" events

This section consists of brief descriptions of Ice Bag for each of Mrs. Miller's three implementations of the water cycle module. In addition to providing a general overview of each event, I include a few segments of transcript from key points during the class session(s). Table 6.3 summarizes Ice Bag along several parameters, including the (module) days on which the event was initiated and terminated and the total duration of the different Ice Bag discussions/activities.

Table 6.3 *General Breakdown of the "Ice Bag" Events Across Implementations*

	Implementation 1	Implementation 2	Implementation 3
Class Session Initiated	Day 12	Day 13	Day 11
Initiated by	Mrs. Miller	Mrs. Miller	Student
Class Session Concluded	Day 14	Day 14	Day 12
Terminated by	Mrs. Miller	Mrs. Miller	Student
Total class time	45 minutes	90 minutes	40 minutes

Note. Implementations 1 & 2 = 14 class sessions. Implementation 3 = 15 class sessions. Times are approximate.

Implementation 1: Ice Bag #1

Mrs. Miller introduced the ice bag phenomenon halfway through Day 12 of the fourteen-day implementation. Prior to the event, the class had been engaged in a discussion about a physical demonstration of the water cycle. The model on display had a collection of ice cubes resting on top of a layer of plastic wrap that had been placed over an aquarium filled partway with hot water (see Figure 6.2a & 6.2b).

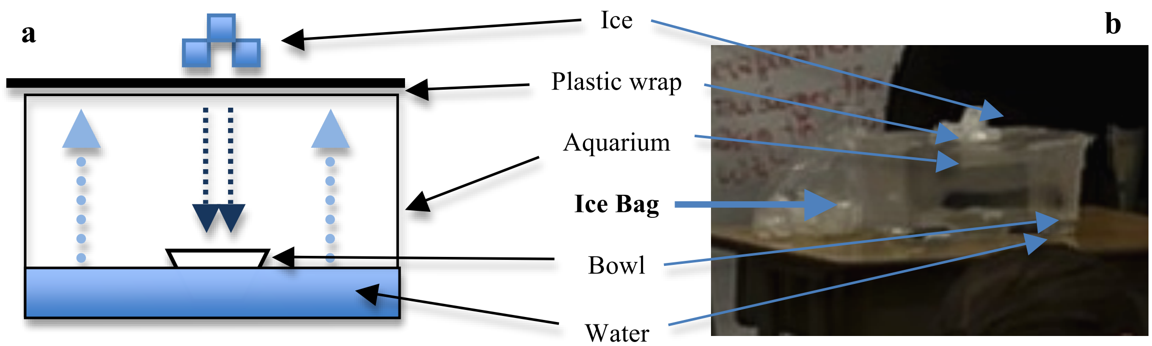

Figure 6.2 *Model representing the water cycle set up by Mrs. Miller for use during Implementation 1.* (a) Schematic of the model (with evaporation and precipitation depicted by light and dark arrows respectively); (b) Photo still of the model as set up by Mrs. Miller.

The class conversation had begun to wind down when Mrs. Miller drew the students' attention to a plastic bag lying adjacent to the aquarium model. The bag contained ice cubes that had been left over from those that had been placed on top of the aquarium. Over time, the bag had accumulated a considerable amount of liquid water on its outside and had generated a small puddle of water on the desktop. When Mrs. Miller lifted the bag overhead, several drops of water "rained" downward onto the ground.

Transcript 6.4a [1.12.24:06]

> **Mrs. Miller**: … I wanted to point something out here. I foolishly did not get a container for this bag (indicates bag of ice), and I assumed that the bag did not have a leak in it. I still don't think it has a leak in it, but you should see all the water up there.
>
> **Anthony**: It's water vapor.
>
> **Mrs. Miller**: From where? (Begins to walk around room, showing bag to students)
>
> **Tommy**: It's condensation. The air around it.

Mrs. Miller: So … the colder the surface, it's going to create condensation, because this water is not coming from the inside of the bag. The bag is not leaking. But you can clearly see, it's wet, so that's how much moisture is in the air (shows student). … So this is not- The water you're feeling is not coming from the inside of the bag. It's coming from the moisture in the air, that's collecting on this…See, but look, this is actually dripping, but there's not a hole in the bag. Here, see it's raining on you, see? I can make it rain right on you.

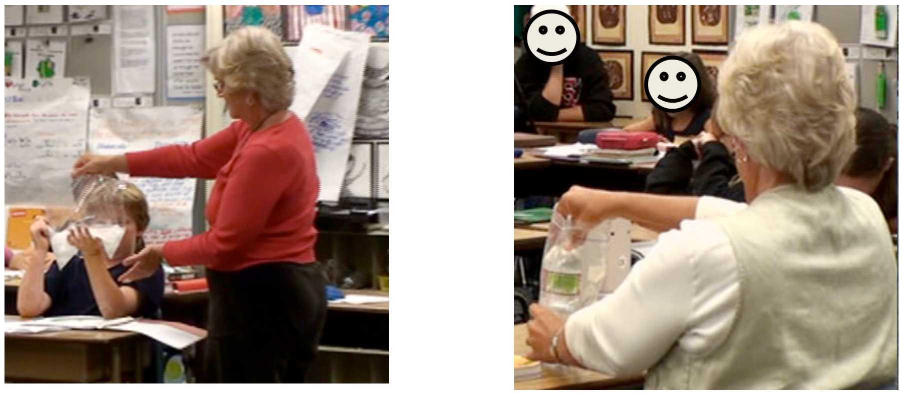

Figure 6.3 *Still Photos of the Ice Bag Event During Implementation 1.* (a) Mrs. Miller displays a dripping plastic bag of ice to a student; (b) Mrs. Miller constructs an impromptu demonstration enacting a student's idea for an experimental set-up.

Having established the water's origin, Mrs. Miller then allowed the conversation to shift elsewhere. After a fifteen-minute hiatus, however, Mrs. Miller elected to revisit the ice bag phenomenon. Stating that she was "not so sure you're convinced that it's coming from the air," she asked where else the water dripping off the bag could have originated. One student responded by offering the suggestion that the water was "dripping through microscope little holes," while another student questioned the water vapor explanation: "How come it's coming through the air?... If condensation was caused by the air…then on any plastic bag, it would come from the air. It's coming from the ice [that] is cold." Despite these student comments, Mrs. Miller permitted the ice bag conversation to drop for the remainder of the class.

During the debriefing discussion following Day 12's session, I shared with Mrs. Miller that I felt the students had interesting ideas about the ice bag phenomenon. As such, I suggested that Mrs. Miller might want to have the students consider the phenomenon further. Mrs. Miller agreed and opened Day 13's session by informing her students that she thought there were some "lingering" questions about the bag of ice. When a student responded by asserting that the water came from the air, Mrs. Miller stated she was unsure that everyone was in agreement on the topic. She then invited the students to briefly confer with their neighbors about the origin of the water dripping off the bag.

After reconvening in whole class mode, several students shared that they thought the liquid water came from the water vapor in the air. Mrs. Miller followed these statements by asking students to "provide evidence" to support this explanation. One student proposed that it was the mixing of the cold air and the room temperature (no elaboration). Another student (Jamie) attempted to connect the phenomenon to the larger water cycle. In his explanation, however, Jamie incorporated the notion that the water appeared as a result of water emerging from *inside* the bag. When Mrs. Miller asked him to elaborate his comments, Jamie back-pedaled and admitted that he was "not sure." After a few minutes of additional discussion, Mrs. Miller elected to revisit Jamie's uncertainty and invited the entire class to help him resolve his confusion.

Transcript 6.4b [1.13.09:58]

Mrs. Miller: …What could we do, or what could we set up that might help Jamie to better understand this? Because he's still not sure, he's not sure whether that water dripped out of the bag or, so what could we do? So turn in your groups, talk for a moment or two in your groups as to, What could we do that would help Jamie to understand this concept better? Okay? Go ahead and do that.

The students went on to describe simple experiments that could "prove" where the water on the bag originated. Mrs. Miller then called on a final pair of students to share their experimental ideas.

Transcript 6.4c [1.13.23:36 – italics indicates speaker's emphasis]

Mrs. Miller: Okay, who's got an idea that they want to share, because I really want to wrap this up, because I really want the time to go off in a different area if possible? Reina, did you and Jasper come up with an idea?

Jasper: You get a cold water bottle, then wipe it off, the water vapor, that was on it from before. And get a plastic bag that's hole-less.

Mrs. Miller: *Holeless*? I think we're creating new vocabulary here, too.

Jasper: Then you put the water bottle in the plastic bag, and then you see if the water, if the condensation, the water vapor condenses on the water bottle or the plastic bag.

Mrs. Miller: Does anybody have a question for Jasper about that idea? What's your question?

The remainder of class was predominantly occupied with the elaboration of Jasper's empirical suggestion. At one point during the discussion, Mrs. Miller even constructed her own model of the evolving experimental procedure (see Figure 6.3b). Mrs. Miller closed Day 13 by inviting interested students to try "something" at home. The following class opened with a student reporting that he had observed his father's beer bottle and noticed that the water on the outside of the cold bottle "didn't taste like alcohol." After few additional student comments, Mrs. Miller brought the ice bag discussion to an end by establishing consensus as to the origin of the dripping water.

Transcript 6.4d [1.14.02:22]

Mrs. Miller: So that's it then, we're pretty comfortable with the condensation that occurs, that liquid comes from where?

Class: Air. Water vapor in the air.

Mrs. Miller: Water vapor in the air, not from?

Unknown Student: The water inside.

Mrs. Miller: Inside the container. That's very good, that's a very difficult concept for a lot of people to understand. We actually showed that that is the case.

Implementation 2: Ice Bag #2

The class session prior to the commencement of the Ice Bag event consisted of small group discussions where students considered different questions concerning water cycle phenomena. At one point during these discussions, a student disagreed with his peers, suggesting that the water forming on the outside of a cold water bottle emerged from *inside* the bottle, rather than forming as a result of condensing water vapor. Although Mrs. Miller probed his explanation lightly in the moment, it was ultimately dismissed in favor of other topics.

During the debriefing session that followed Day 12, Mrs. Miller and I discussed the opposing views regarding the origin of the water. We agreed that it was a debate worth pursuing, especially in light of how stimulating the question had been for the students the previous year. I suggested that she could potentially use a plastic bag of ice (similar to what had been used the previous year) as a foundation for further discussion [2.12 - DBRF]. Mrs. Miller subsequently opted to subtly introduce the topic by inviting her students to make their own observations of small ice bags.

The first half of the following session was spent wrapping up previous discussions. Midway through the class, however, Mrs. Miller halted the conversation and shifted the topic of the students' attention to the ice bags.

Transcript 6.4e [2.13.26:26]

Mrs. Miller: I would like to, if you don't mind, if we could just suspend this conversation, don't forget it, just suspend it for right now. Because I am ready, I have something prepared, that I think might, I'm not sure, maybe it will end up with more questions afterwards, but I thought this would be a good time to try this… The first thing I want you to be doing is observing, okay? I want you to be observing and thinking about what you're observing, that's how I want to say it, okay? So I will tell you that in this orange container … is water in a different state of matter. So Troy, what is this water that's in a different state of matter, what do we call this?

Troy: It's ice.

Mrs. Miller: So this is ice, and I wish for you to place it on your table on a paper towel, and then you're just going to observe it.

Mrs. Miller distributed small bags of ice to her students and circulated among them as they record their observations (see Figure 6.4). Upon reconvening as a class, the students quickly agreed that water is forming on the outside of the bag. One student, Martin, then proposed that the water originates from the water vapor in the air.

Transcript 6.4f [2.13.47:31]

Martin: I think it's the moisture in the air getting cold so it's turning back into water form, and collecting on that bag, since that bag is the thing that's cold.

Mrs. Miller: So are you convinced that that water then isn't coming from the inside of the bag?

Martin: Yes, I am convinced of that.

Mrs. Miller: Is there anybody else in here that agrees with Martin that the water on the outside of the bags is not coming from the inside of the bag, raise your hand if you agree with Martin on that one? (many hands) Now, so I want everybody to be voting here, put your hands down, how many of you think that the water on the outside of the bag is coming from the inside of the bag? (some hands). So we seem to have 2 schools of thought here, we have 1 thought that the moisture on the outside of the bag, … Is coming from the water vapor in the air that is collecting on this cold surface, correct, … The other group, Troy, thinks that the water on the outside of the bag actually is somehow coming out of these sealed bags, and you notice, the bag is sealed (turns). What might be a way that we could prove your theory (looks at Martin) and what might be a way we can prove Roland and Jimmy's theory?

For the next ten minutes, Mrs. Miller encouraged students on both sides of the debate to elaborate their explanations and develop potential empirical methods to “prove their theory.” At the conclusion of the day’s session, Mrs. Miller invited each student to “take a stand” with respect to the origin of water and record their ideas in their journals.

Figure 6.4 *Still photos of the Ice Bag event during Implementation 2.* (a) Mrs. Miller holds up a sample plastic bag with ice (circled), (b) student feels the outside of the bag of ice, (c) student inserts a bag of ice with added food coloring into a second plastic bag.

During the debriefing interview that followed the day's session, Mrs. Miller expressed surprise that her students didn't immediately understand that water originates from the water vapor in the air. As a result, she considered having her students design simple experiments the following session, in order to move them forward in their thinking [2.13 - DBRF]. During the interval between our debriefing interview and the next class session, however, two students independently shared additional thoughts about the ice bag. As a result of their comments, Mrs. Miller opted to alter the following session's lesson plans. She instead opened discussions on Day 14 by recapping the previous day's activities and inviting one of the two students, Charlie, to repeat his proposal.

Transcript 6.4g [2.14.03:27]

Mrs. Miller: …However, at the end of the day, after our science people had already left, Charlie was sitting there pondering that bag that was ice yesterday, now it's just water. And Charlie, you want to share with the class what you came up with, what you thought?

Charlie: I think the way to prove both theories is dye, it's inside the water and then freeze it, so we have colored ice, so we know that, if the water is coming from the inside of the bag, that the water will be colored, not clear.

The students agreed that Charlie's experimental procedure would indeed show whether the water condensed from water vapor or seeped through the bag. Mrs. Miller then invited the second student, Jimmy, to share his reasoning as to why he thought the water could emerge from the *inside* of the bag.

Transcript 6.4h [2.14.06:12]

Mrs. Miller: But Jimmy came up with something yesterday that really intrigued me, and I asked him, what was the evidence that he had for the fact that the water comes from the inside of the bag and somehow it was able to seep to the outside of the bag? … Elaborate on that for us, for the class?

Jimmy: Have you ever taken the trash out, and I just got a new trashcan that has that top over it. And it has the top over it, you can still smell it, but it's shut. So how can the smell get out, if it's shut tight?

Mrs. Miller: So you're saying if odors can get through the plastic?

Jimmy: Then why shouldn't (points water bottle).

Mrs. Miller: Then perhaps maybe why couldn't water?

Jimmy: And gas.

The students discuss Jimmy's ideas for a few moments, and Mrs. Miller distributes a new set of ice bags. Having taken Charlie and Jimmy's comments under consideration, she then directed the student groups to add food coloring and/or aromatic extract to their bags prior to sealing them (see Figure 6.4c). For twenty minutes, Mrs. Miller circulated among the groups as the students observed their bags.

Upon reconvening as a class, the students were in consensus that the water forming on the bag was clear (not colored), although the bags *did* release a smell. One student proposed that reason for this result was that the odor was able to get through the bags, but the water could not. Another student, Tonya, questioned how the water could be coming from the air, when "there's no source of water anywhere for it to be in the air." Students answered that the water could come from a variety of places, including evaporated water and people's breath. Tonya then countered their arguments by asking how water could be "floating around and just when it reaches something it gets wet all of sudden." Under time pressure, Mrs. Miller brought the class session, and the module implementation itself, to a close, without having resolved Tonya's question.

Implementation 3: Ice Bag #3

The ice bag phenomenon was initially recognized by a student midway through Day 11 of Implementation 3. The class had been examining and discussing an aquarium demonstration of the water cycle a model similar to that which had been constructed for Implementation 1 (see Figure 6.5). At one point in the discussion, Mrs. Miller substituted an ice pack inside a plastic bag for the free ice cubes on the top of the plastic wrap. She then asked her students to predict the outcome of the now altered set-up (see Figure 6.6a). As the students considered the new scenario, a student (Ben) drew the class's attention to the "fog" forming on the ice pack itself.

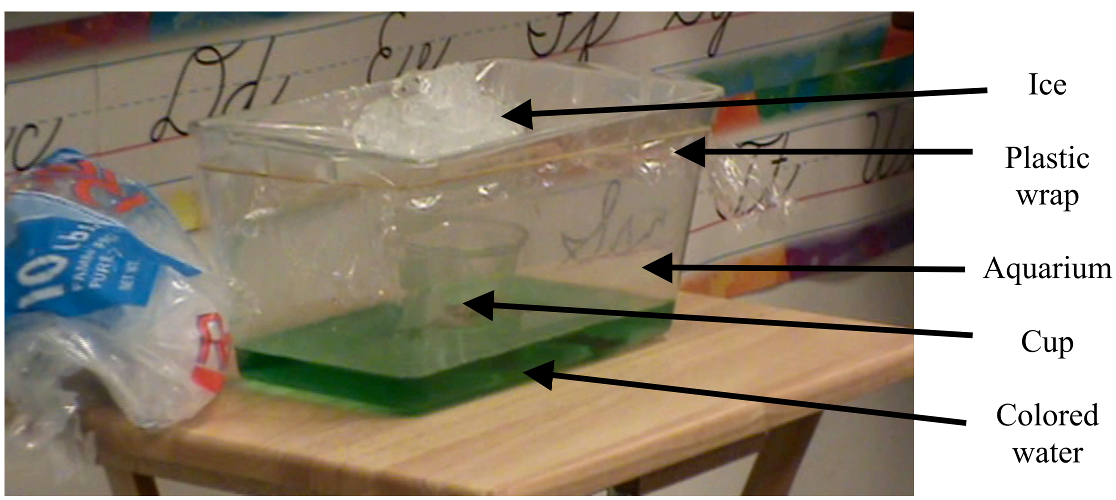

Figure 6.5 *Model Representing the Water Cycle Set up by Mrs. Miller for Use During Implementation 3.*

Transcript 6.4i [3.11.33.48]

Mrs. Miller: So what did Ben want to say?

Ben: The point of the ice pack is so nothing can get out whatsoever. But if you look, that's condensation, because the water vapor gets attracted to the cold, like in the bag, so it gets that fog around it. So what's going to happen here, that's why we put ice on it and not an ice pack, because they're frozen.

Mrs. Miller: So you notice something here, you notice what, that?

Ben: There's already fog.

Mrs. Miller: There's like a fog here.

Mrs. Miller acknowledged Ben's observation and probed his observations slightly. After a few moments, however, Mrs. Miller returned the students' collective attention to the aquarium model demonstration and shifted the focus away from the ice bag (ice pack). The topic was not revisited during the remainder of the Day 11 session. [NOTE: Due to scheduling conflicts, I was not present during the Day 11 session nor did Mrs. Miller and I have an opportunity to debrief immediately following the session. Mrs. Miller did summarize the session for me following class, however, and in her summary she did not mention Ben's observation of the ice pack bag.]

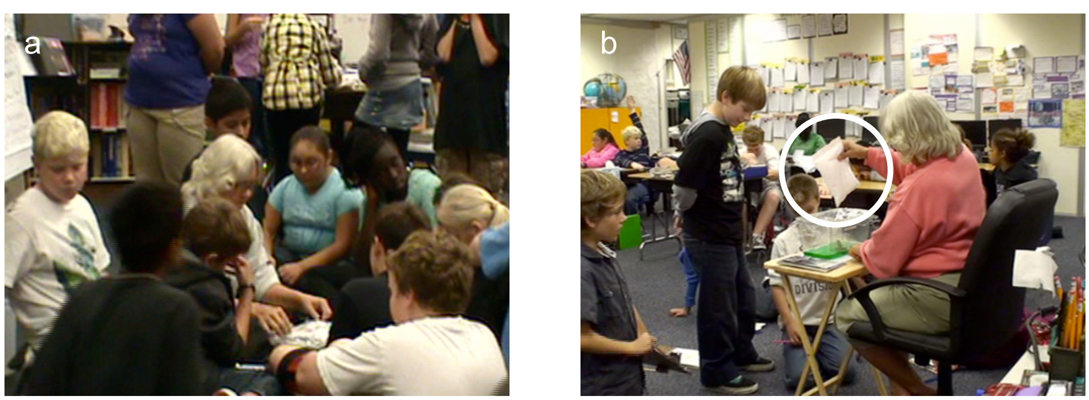

Figure 6.6 Still Photos of the Ice Bag Event During Implementation 3. (a) Mrs. Miller places an ice pack on top of an aquarium model of the water cycle; (b) Mrs. Miller holds up an ice pack inside a plastic bag (circled) as students look on.

Prior to class on Day 12, Mrs. Miller again set up the aquarium model. This time, however, she placed the ice pack directly on the plastic wrap, without having placed it first in a plastic bag. Mrs. Miller opened Day 12's discussion by having the students review their thoughts on the aquarium model. During this discussion, a student (Sam) pointed out that the ice pack itself was wet and raised the possibility that the wet ice pack could be a source of the water visibly dripping down from the plastic wrap into the aquarium. Mrs. Miller acknowledged Sam's contribution, but dismissed it as a "whole other question." She quickly moved to resume conversation about the demonstration itself, although she first observed that, "You can…see all the water [sitting on the plastic wrap] came from the outside of the [ice pack], not the inside. There's no leaks in this [ice pack]. Feel it (turns to a student). There's no leaks." The class then returned to a discussion focused on the aquarium model for a few minutes. At that point, another student (Nathan) returned to Sam's comment about the ice pack. Nathan explained that while he agrees that the bag itself "sweats," he believed that it is *not* responsible for the water dripping down from the plastic wrap. Some back and forth dialogue then took place as the students attempted to definitively establish the origin of the water dripping down into the aquarium. Another student, Jonah, disagreed with Nathan's explanation, proposing instead that ice crystals form on the outside of the ice pack bag when it froze and subsequently melted off the bag. Other students then volunteered their thoughts, although the conversation quickly meandered to different topics.

A few minutes later, Mrs. Miller refocused the class on the ice pack, explicitly asking her students where the moisture dripping off the ice pack came from (see Figure 6.6b). One student responded that the water comes from the "air and the moisture in it."

Another added that, “There’s always moisture in the air, because water is always evaporating. It is never just sitting around.” Several students offered comments to the contrary, however, stating that if that was the case that everything “would be constantly wet” and there would be “mold growing everywhere.” Further conversation ensued, with Mrs. Miller repeatedly pushing her students to account for where the water on the ice pack originated. One student eventually raised the possibility that it was the interactions between “hot/cold” that produced the water. Others students argued that the water had to come from inside the bag. Mrs. Miller challenged the “inside” point-of-view, however, asserting, “The [ice pack] doesn’t have a hole in it.” She then invited a student, Larry, to repeat his earlier explanation for how water could come from the air.

Transcript 6.4j [3.12.31:00]

Unknown Student: Where is the moisture coming from?

Mrs. Miller: Exactly, so listen again, just listen to what Larry says and see if you agree with what Larry says. Explain this again, Larry, explain this again, stand right over here and explain.

Larry: The water in the air gets on it, and there's still ice in here, so the ice probably freezes it.

Mrs. Miller: Freezes it, do you think? And where does that moisture that's on the outside here coming from?

Larry: The moisture is in the air.

Mrs. Miller then asked whether anyone agreed with student Larry. Several students indicated that they did, while others disagreed, countering that if Larry were right, then “everything would be molded/soaked all the time.” Another student (Mary) then expressed a desire to pose a question to the students that believed the water came from the air.

Transcript 6.4k [3.12.32:07]

Mrs. Miller: Mary, what did you want to say?

Mary: I have a question for the people who think there's moisture in the air. Why is the moisture on the ice pack and not anywhere else?

Mrs. Miller: Say it again.

Mary I have a question for people who say there's moisture in the air, how come there's only moisture on the ice pack and not anywhere else?...

Mrs. Miller: (turns to the class) What do you think?

Although a few students proceeded to respond to Mary's question, the discussion meandered and resolution was never achieved. Eventually, a series of students made observations relating to scenarios only distantly related to the ice pack (e.g. water bottles in lunch bags, reusable water bottles, the water cycle model). Mrs. Miller took up one of these comments by inviting her class to turn its attention back to the aquarium demonstration [3.12.39:33]. This shift in focus concluded the discussions concerning the ice pack bag for Implementation 3, although the class did consider other examples of condensation (e.g. water forming on cold bottles and cups) at a later time.

6.5 Analysis of "Ice Bag" events

A comparison of Mrs. Miller's practice across Day 1 events reveals several similarities and differences in how Mrs. Miller engaged with her students. Some of these findings are consistent with those that emerged from the analyses of Day 1, while some are dissimilar. The subsections that follow present these results in detail. The final subsection summarizes the Ice Bag findings and describes how they support a claim that Mrs. Miller changed with respect to how she responded to her students' thinking over time.

Similarities

There are several consistencies to be found across the three Ice Bag events. First, the discussions and activities concerning the ice bag phenomenon occurred late in each of the three implementations (Day 11 or later), occupied the majority of at least one class session, and began with observations of a physical demonstration (e.g. dripping ice bag, fog on ice bags, water on ice pack). Second, as before, Mrs. Miller allowed considerable room for her students to express their ideas, ask questions, and respond to one another's comments during the ice bag discussions and activities. Throughout the Ice Bag events, Mrs. Miller asked numerous open-ended questions and consistently elicited students' thoughts and explanations. She also asked plentiful follow-up questions, providing time and space for her students to clarify and elaborate their ideas. To exemplify these recurring practices, I include two additional segments of transcript below. The first is taken from the first implementation, while the second transcript is taken from Implementation 2.

Transcript 6.5a [1.12.31:13 – italics indicates speaker's emphasis]

Jack: If you did that with a *different* drink, that would work.

Mrs. Miller: Now *why* would you want to use a different drink? Other than water?

Jack: 'Cause then you have no clue if it's leaking or not. I mean *that* could be water from a leak or water from the condensation.

Mrs. Miller: Like, what would you want to freeze?

Jack: You could use, like … like soda or something, and then water appeared in the *bag*, you know it's- And you, like, *drank* it and you found out it wasn't like, soda or something-

Jasper: Oh yeah. I get what you're trying to say-

Mrs. Miller: OK. Alright. Go ahead. Go ahead. Finish what you're saying. (…)

Jasper: I get what Jack's saying. Like, if you use, like, a different *drink*, like let's say, *orange juice* or something or *soda*, um- If it was *leaking*, … if you thought it was leaking *water*, you would know if it was from the *condensation*, because the orange juice is *yellow*, it's not all like clear like *water*

Transcript 6.5b [2.13.53:35]

Tonya: What my opinion is, I have to agree with Jimmy that somehow the water is getting out, because just to think, if we had a plain simple bag with no water in it, it would stay dry, it wouldn't. They said the air around it, because if we had just a clean, simple bag, you don't feel it wet, and there's air around us, and it's dry. But if you put water and ice in it, then it will become wet, so I think it has to do somehow with the water coming out...

Mrs. Miller: Let me- I'm going to be quiet. Charlie, you can speak to that.

Charlie: I was just saying, the reason for that is because the water and ice is so cold that when the water vapor from outside touches it, it turns back into a liquid.

Mrs. Miller: Why is that, why do you think that?

Charlie: Because heat evaporates water, so cold would liquicize the water…And then I think it proves that the plastic is airtight, by maybe taking some strings and maybe a string, one on each corner and then one in the middle, taping them there and putting water on it, to show that the water can't leak through the bag.

These two segments demonstrate that Mrs. Miller made room for her students to offer their ideas and questions. The transcripts also show that Mrs. Miller followed up her students' comments with questions aimed at clarifying and/or elaborating the students' ideas. When Jack proposed that the experiment would benefit from using a different drink (Transcript 6.5a, line 1), for example, Mrs. Miller asked him *why* he would choose to use a different drink (line 2). Similarly, Mrs. Miller asks Charlie *why* he thinks that water vapor turns back into a liquid in Transcript 6.5b (line 9). The segments displayed above also show that Mrs. Miller encouraged her students to extend and elaborate *each other's* comments. For example, Mrs. Miller invited Jasper to finish his train of thought when he interjects that he understands Jack's reasoning behind an experimental modification (Transcript 6.5a, line 9). She also allowed Charlie to respond to Tonya's query, rather than addressing the question herself (Transcript 6.5b, line 6).

Another similarity found across all implementations is that Mrs. Miller highlighted specific student ideas for her class to consider and reason about further. For example, during Ice Bag #1, Mrs. Miller encouraged her entire class to consider and elaborate Jasper's experimental protocol for a significant segment of the session. This is in spite of expressing her original intent to have the class "go in a different direction" after Jasper shared his ideas (Transcript 6.4c, line 2). Mrs. Miller similarly invited students to consider Jamie's reasoning behind his "alternative" explanation during Ice Bag #2 [Transcript 6.4h, lines 1-3] and asked her students what they thought of Mary's question regarding why water doesn't form on "anything else" during the third ice bag event [Transcript 6.4k, lines 1-7]. Thus, Mrs. Miller's comments and questions show that she regularly made room for student ideas, encouraged her students to clarify and elaborate their ideas, and placed students' ideas as the focus for further discussion at different points during the three Ice Bag events.

A final similarity to be found across Ice Bag events is that while there were no explicitly stated content objectives for the water cycle module (see Sections 1.3 and 3.3), there is consistent evidence to suggest that Mrs. Miller wanted her students to understand that the water forming on the bag of ice originated from water vapor in the air. First, Mrs. Miller made several explicit statements regarding the water's origin. For example, upon initially lifting the ice bag off the table Mrs. Miller stated that, "This water is not coming from the inside of the bag… But you can clearly see, it's wet, so that's how much moisture is in the air…The water you're feeling is not coming from the inside of the bag. It's coming from the moisture in the air, that's collecting on this" (Transcript 6.4a, lines 7-10). Mrs. Miller issued a similar comment during Ice Bag #3: "All the water in here came from the outside of the bag, not the inside" [3.12.03:45].

Another piece of evidence to support Mrs. Miller's content goals came in the form of comments Mrs. Miller made in each of the three Ice Bag events concerning the absence of leaks or holes in the plastic bag(s). During Ice Bag #1, for example, Mrs. Miller asserted, "The bag is not leaking…This is actually dripping, but there's not a hole in the bag" (Transcript 6.4a, lines 8 and 11). She issued similar statements in both the second and third Ice Bag events (e.g. "This is a leak-proof bag, not like baby diapers" [2.13.51:44], and "There is a *lot of* water on the outside of this pack, but this pack is not leaking" [3.12.03:34]).

Additionally, Mrs. Miller invited students she knew to have the "correct" understanding to share their reasoning with the rest of the class. During Ice Bag #2, for example, Mrs. Miller asked Martin to share his "theory" about the origin of the water (which she already knew to be scientifically accurate) with his peers (Transcript 6.4f, lines 1-2). She also invites Larry to repeat his explanation (which she knew to be correct) during Ice Bag #3 (Transcript 6.4j, lines 2-3).

Finally, Mrs. Miller's made specific statements during her debriefing that seemed to indicate she wanted to have her students understand condensation. For example, she expressed difficulty in understanding why her students weren't clear on the origin of the water in one such session [2.13 - DBRF].

Differences

The differences in Mrs. Miller's practice across Ice Bag events could be grouped into categories similar to those described for the Day 1 event. While the category titles are the same, however, the *specific* components included therein are not necessarily aligned with those presented previously. For Ice Bag, the "Launch" category consists of the differences regarding how the three events emerged over the course of the implementations, the "Facilitation" category involves the differences concerning how Mrs. Miller facilitated her students' interactions and exchanges during discussions/activities, and the "Conclusion" category consists of the collection of differences concerning how the Ice Bag discussions/activities came to a close. The following paragraphs describe and exemplify these differences.

<u>Launch differences</u>:

Although the dripping ice bag emerged as a discussion topic in each of the three implementations, Ice Bag was not an arranged event that was necessarily going to emerge at some point during the module implementation. The manner in which the subject developed over the course of the module varied across implementations. Specifically, the launch of the three events differed with respect to *who* initiated the event and *how* the event was introduced. Mrs. Miller initiated Ice Bag #1 by spontaneously picking up a bag of ice lying adjacent to the aquarium model (Figure 6.2b). While these actions effectively introduced her students to the ice bag phenomenon, Mrs. Miller didn't really engage them in further exploring the topic until the following day. It was only after Mrs. Miller and I discussed the students' interesting comments during our debriefing interview that she challenged her students to further articulate and explore their ideas concerning the phenomenon [1.12 - DBRF].

In contrast to the spontaneous launch of Ice Bag #1, the phenomenon of the dripping ice bag was introduced during the second implementation after careful planning and preparation. When students disagreed as to why fog appears on a cold water bottle at the end of Day 12, Mrs. Miller and I concurred that it would be worthwhile to engage students in further discussion about condensation [2.12 - DBRF]. As such, Mrs. Miller introduced the event the following session by distributing sealed bags of ice and asking her students to *observe* the bags (Transcript 6.4e, lines 9-10) during the following session. She later asked them to account for their observations.

Whereas Mrs. Miller initiated the first two Ice Bag events, a *student* was responsible for initiating Ice Bag #3. Specifically, Ben drew the class's attention to the water forming on the outside of the ice pack lying on top of the aquarium (Figure 6.6a, Transcript 6.4i, lines 3-4). While the topic was not pursued at length at that time, a second student noted the same phenomenon the following class session. After several students offered additional thoughts about the dripping ice pack, Mrs. Miller highlighted the pack as a focal point for the entire class's attention. She explicitly requested that her students account for the origin of the water.

As described above, each of the three Ice Bag events eventually transitioned into a discussion concerning the origin of the bag's dripping water. However, the process by which that discussion was launched differed across the three implementations in several ways. First, Mrs. Miller introduced the topic in Ice Bag #1 and #2, while students introduced the topic in the final event. Second, Ice Bag #2 began with small group observations, whereas the event emerged as a result of spontaneous observations of a class demonstration in the first and third implementations. Finally, discussions about student conceptions of condensation during debriefing seemed to prompt some of Mrs.

Miller's Ice Bag launching actions in Ice Bag #1 and #2, while this was not the case for Ice Bag #3.

<u>Facilitation differences:</u>

As described previously in the "similarities" section, Mrs. Miller made room for her students' ideas concerning the ice bag phenomenon in all three Ice Bag events. However, her practice to support and encourage scientifically *incorrect* explanations for the origination of the dripping water seems to differ across implementations. This change in Mrs. Miller's practice is reflected in the comments she makes and the questions she asks over the course of the three Ice Bag discussions and activities.

Mrs. Miller introduced Ice Bag #1 by "telling" her students that the dripping water isn't coming from inside the bag [Transcript 6.4a, lines 7-10]. Although Mrs. Miller later acknowledged that some students might have alternative explanations for where the dripping water originated, she did not probe or encourage her students to elaborate such explanations. For example, following a student's suggestion that water could be emerging through microscopic holes in the plastic bag, she responded, "Do you really believe that? Do you really believe that?" and allowed the conversation to drop. When she later revisited the topic, she used Jamie's uncertainty as the grounds for designing experiments, asking her students what they could do to "help Jamie to better understand this concept" (Transcript 6.4b, lines 1-4). Thus, Mrs. Miller's comments during Ice Bag #1 seem to suggest that she is less concerned with having her students elaborate alternative explanations and more concerned with them acquiring the correct explanation.

In contrast, Mrs. Miller's questions and comments during the second and third Ice Bag events seem to encourage students to share, develop, and elaborate alternative explanations. For example, after Martin proposed that the water forming on the ice bags came from the air during Ice Bag #2, Mrs. Miller asked if there were any students who instead thought that the water was coming from inside the bag (Transcript 6.4f, lines 7-8). After several students raised their hands, she went on to invite both "schools of thought" to generate a means to "prove" their "theory" (Transcript 6.4f, lines 12-13). Mrs. Miller later invited student Jimmy to share his reasoning behind thinking that the water emerges through the plastic (Transcript 6.4h, lines 1-3). Such comments suggest that she *anticipated* that students might think water seeped through the plastic. What's more, her invitations served to *encourage* students to pursue, develop, and elaborate such alternate explanations. This is echoed in Ice Bag #3, when Mrs. Miller opted to invite her entire class take up and respond to Mary's query, rather than electing to correct or challenge Mary's incorrect thinking herself (Transcript 6.4k, line 7). Thus, while Mrs. Miller arguably made comments suggestive of a condensation content goal during all three ice bag events (see similarities section), her questions and statements during Ice Bag #2 and #3 support an additional intent to have her students develop, reason about, elaborate, and justify explanations for the ice bag phenomenon.

A second difference with respect to how Mrs. Miller facilitated the three sets of discussions/activities around the ice bag phenomenon concerns her practice of requesting student to justify and/or explain their responses. While Mrs. Miller engaged her students in talking about *where* the water originated in Ice Bag #1, Mrs. Miller rarely encouraged her students to provide evidence for, justify, or provide a mechanism behind their answers. The few occasions where she *did* request such justification were generally followed by a quick acknowledgement and not pursued further. It is therefore unsurprising that the students provided reasoning behind their answers only infrequently during the first Ice Bag event.

In contrast, Mrs. Miller pressed her students for justification more regularly during the second and third Ice Bag event. For example, in Ice Bag #2, Mrs. Miller asked Martin to share and *explain* his theory for how the ice bag got wet during discussion. She later requested that her students "take a stand" and record *why* they thought as they did in their journals (no matter the stand they took). Similarly, she went on to ask her students *why* water could be felt on the ice pack and not in the air after Larry finished his "correct" explanation in Ice Bag #3 [3.12.31:00]. In all of these cases, Mrs. Miller pushed her students to provide more information beyond a simple one-word answer. Interestingly, this practice of Mrs. Miller's seemed to compel the students to offer their reasoning *even when not prompted her directly*. While only a few students provided their reasoning in Ice Bag #1, there are numerous occasions where the students spontaneously justified their responses in Ice Bag #2 and #3. Consider the six student statements below. The first set of two comments was taken from conversations during Ice Bag #1, the second two from Ice Bag #2, and the third set from Ice Bag #3. These comments are representative of student comments during the respective Ice Bag events.

Transcript 6.5c – [italics indicates speaker's emphasis]

Ice Bag #1:
Matthew: Our group believes that it comes from the water vapor in the air, not from the inside of a bag.

Andre: We think the water vapor collects from the air.

Ice Bag #2:

Tonya: What my opinion is, I have to agree with Jimmy that somehow the water is getting out, because just to think, if we had a plain simple bag with no water in it, it would stay dry, it wouldn't. They said the air around it, because if we had just a clean, simple bag, you don't feel it wet, and there's air around us, and it's dry. But if you put water and ice in it, then it will become wet, so I think it has to do somehow with the water coming out

Bethany: I think when fog is going on the side of the bag it might be because of how cold it is. Because it's like on a window like when it's really cold outside, you feel the window and it's cold. And so when you breathe and go hah, your breath is really hot and you can see faded fog on the window. So I guess that's like when your hand has heat, so when you touch it, it gets fog onto the bag, that's what I'm thinking.

Ice Bag #3:

Samuel: I can see, why I kind of thought that- …My dad told me if I drip too much water on my carpet, mold would grow. It's really, there's a couple pounds, there's a cup of water there, it's more like, it would be small, small. Getting a drop and cutting it super tiny, and spread *that* little tiny into all the air in this room.

Nathan: Earlier Jonah was saying that there's crystals on the outside. Do you know when you get ice cream in the freezer for a long time, and then you eat it, it gets all *icy.* I think that's what happened to the ice pack. On the outside, it got all icy, really, really cold, and it made little ice crystals. So it melted, and that's what made it sweat, I think, and that's what made the puddle of stuff.

Notice that the first two student comments consist of only a response statement (e.g. water vapor comes from the air), while the latter four include (unprompted) reasons behind the response. The students' reasons include describing a related scenario, creating an analogy, and relaying a conversation with a knowledgeable other (e.g. Samuel's Dad). This student practice of supplying justification in Ice Bag #2 and #3 is in stark contrast to that displayed during the first Ice Bag event, where the students rarely did so. It appears as if Mrs. Miller and her students developed the classroom norm of the students defending their responses during discussion in the two later implementations. This norm was likely nourished by Mrs. Miller's greater propensity to issue follow up questions and probes, as discussed above.

Conclusion differences:

An examination of the three Ice Bag conclusions yields differences as to who terminated the event and how the event came to an end. Ice Bag #1 concluded in the first few minutes of the final day of the implementation. Mrs. Miller opened Day 14 by inviting students to share additional thoughts about the previous day's discussion. After a few student comments, Mrs. Miller quickly brought the event to a close by asking her students two "fill-in-the-blank" type questions, and having her students filling in the appropriate terms (Transcript 6.4d, lines 1-5). She then praised her students for coming to an understanding of "a very difficult concept" (Transcript 6.4d, lines 6-7) and proceeded to shift gears by introducing a new subject, "What is precipitation?" Although Mrs. Miller subsequently requested that her students "keep in mind" their previous discussions when responding to the question, Mrs. Miller's students did not attempt to link their ideas about precipitation with those concerning evaporation or condensation. In truth, the Ice Bag discussions and activities seem to be detached from the precipitation discussion that followed.

The second Ice Bag event also concluded on the final day of the implementation. Mrs. Miller began the session by modifying the previous ice bag protocol to reflect Charlie and Jamie's ideas (Transcripts 6.4g and 6.4h). The class eventually shared their findings, and several provocative comments were made, including Tonya's query regarding how water could just be "floating around." Due to time constraints, however, the discussion ended without resolving Tonya's concerns. Similar to the first implementation, there was no revisit of condensation or related topics following the abrupt conclusion of Ice Bag #2, although this is arguably because the final moments of the discussion were also the final moments of the module itself.

Ice Bag #3 was introduced on two separate occasions: the first occurring midway through Day 11 and the second taking place early on Day 12. Both instances consisted of students (Ben and Sam) highlighting the phenomenon of the wet ice pack. Throughout the third Ice Bag event, the students and Mrs. Miller shifted between discussing the aquarium model and discussing the ice pack itself. The event eventually "ended" when a series of student comments focused on non-ice pack subjects, and Mrs. Miller pursued one of them, rather than returning to the ice pack. While this shift "officially" marks the conclusion of Ice Bag #3, the topic of condensation continues to be considered, debated, and discussed for several more days, with the students making observations of both cold water bottles and cold liquids in plastic cups. Thus, in contrast to the previous two implementations, the third ice bag event merges fluidly into the next discussion at its end.

Summary and synthesis: "Ice Bag" events

As was the case for Day 1, Mrs. Miller exhibited several instructional practices that were consistent across the three Ice Bag events. Mrs. Miller elicited student ideas during discussion and placed them on display for others to consider, she encouraged her students to build upon each other's ideas, and she engaged her students in activities with the intent to help them develop a greater understanding of condensation. Several of Mrs. Miller's moves, however, differed noticeably across the events. First, while she was responsible for both introducing and sustaining the first two Ice Bag events, her students initiated the final event. Mrs. Miller was instead responsible for highlighting the topic in

Ice Bag #3 and perpetuating the discussion through her follow up probes and redirections. Second, the methods Mrs. Miller employed in facilitating her students' discussions suggest changes in her willingness and ability to encourage students to articulate and elaborate alternative explanations. While seemingly reluctant to pursue such explanations during Ice Bag #1, she appeared to encourage such explanations during Ice Bag #2 and #3. Finally, Mrs. Miller seemed to differ with respect to how she allowed the events to end. Instead of bringing the events to an abrupt close, as was the case with Ice Bags #1 and #2, Mrs. Miller permitted her students to move to related topics in the final Ice Bag event.

Synthesizing across these findings from the Ice Bag analyses, there are two claims that can be made with respect to changes in Mrs. Miller's practice. Both of these claims are consistent with a shift in Mrs. Miller's ability to attend and respond to her students' thinking. First, while Mrs. Miller encouraged her students to share their thoughts in all three events, her openness to having her students entertain, communicate, and elaborate explanations that were counter to that which is "scientifically accepted" seemed to increase over time. [Although it is beyond the scope of this study to definitively account for this increase in Mrs. Miller's openness to alternative explanations, it is possible this may be a result of a change in Mrs. Miller's understanding of what science *is* or what it means *to do science*. This, however, is a possible topic for pursuit in a future study.] The plethora of opportunities for her students to propose, consider, and debate alternative explanations in the second and third event are evidence to support such a claim. Mrs. Miller's greater willingness to allow room for her students to express and develop such explanations arguably afforded her more access to her students' thinking and, thus, provided more possibilities for her to take up and respond to that thinking.

Second, Mrs. Miller seemed to change with respect to how she allowed the topic of the dripping ice bag to enter and exit discussion. Mrs. Miller herself introduced the topic during the first and second Ice Bag event, albeit spontaneously in Ice Bag #1 and via planning in Ice Bag #2. Mrs. Miller was also responsible for bringing the first two events to a close. Interestingly, the major discussions surrounding the phenomenon only took place *after* a debriefing discussion with a professional developer in both events. While this might not seem consequential, I would argue that it was through these debriefing sessions that Mrs. Miller came to recognize the subject's rich potential and, thus, decide to incorporate it into the following session.

In contrast, Mrs. Miller wasn't responsible for introducing or concluding Ice Bag #3; her students both initiated and terminated the event. Mrs. Miller instead encouraged discussion on the topic once it had been raised and allowed the discussion to move on once students had considered the phenomenon at length. Thus, it appears as if Mrs. Miller was being more responsive to her students' thinking in Ice Bag #3 than in the previous two events. She responded to her students' questions and comments by placing the phenomenon at the center of discussion and did so once again when she allowed the discussion to move away from the ice bag and onto an emergent student comment.

6.6 Comparison across the two "events"

As described in section 6.1, Day 1 and Ice Bag provided two contexts in which to examine Mrs. Miller's instructional practice. The Day 1 sessions occurred at the very beginning of each of the three module implementations and began with a question about a disappearing puddle. The Ice Bag sessions, on the other hand, occurred towards the end of the three module implementations and did not necessarily begin with a similar question or focus. Despite the disparate nature of the two different events, an examination of Mrs. Miller's practice across Day 1 and Ice Bag, as evident in her classroom discourse and comments made during debriefing, supports several claims:

1. Mrs. Miller consistently elicited student comments and encouraged her students to listen to and elaborate each other's ideas across both events in all three implementations.
2. Although the format of the responsive curriculum did not explicitly list content elements or objectives, Mrs. Miller's questions and statements recurrently focused her students' attention on specific aspects of the water cycle (e.g. evaporation and condensation).
3. Mrs. Miller was more likely to encourage her students to share, elaborate, and justify alternative explanations for natural phenomena (i.e. a disappearing puddle and water dripping from a bag if ice) over the course of the three implementations.
4. Mrs. Miller was more likely to allow student comments to provide the basis for future discussion, both in-the-moment and on subsequent sessions, in the latter two implementations and especially during implementation three.

Collectively, these claims seem to suggest Mrs. Miller's changed in her responsiveness to her students' thinking over the course of the three implementations. Mrs. Miller anticipated and encouraged alternative explanations in the latter two implementations, as evident by her comments and questions directed towards her students. It is therefore unsurprising, given these comments, that her students posited an increasing number of alternative explanations over time. Such alternatives, and the reasoning behind them, provided Mrs. Miller and her students with a larger repository of ideas from which to choose subsequent directions for discussion. It is possible that as Mrs. Miller became more comfortable with allowing her students to consider and reason about such diverse ideas, she became more at ease with having the ideas be the focus of additional discussion.

These analyses show that Mrs. Miller seemed to be more ready to take up her students' ideas and place them as the focus for further conversation and activity, both in the moment (e.g. the use of student comments in determining Day 1's EGD during Implementation #3) and during future class sessions (e.g. the use of student ideas the modified ice bag protocol in Ice Bag #2). In conclusion, these data support the claim that Mrs. Miller changed in her responsiveness over time, specifically in that she was more likely to make room for, take up, and pursue her students' thinking (whether scientifically "accurate" or not) in later implementations.

CHAPTER 7: DISCUSSION

This final chapter utilizes the findings presented in Chapters 5 and 6 to answer the original research questions. Chapter 7 also describes some of the strengths, contributions, and limitations of this case study. In Section 7.1, I revisit the original research questions and discuss how the findings answer these questions. Section 7.2 consists of a discussion of the strengths and contributions of this research, while Section 7.3 describes some of its limitations and points out areas for future study. Finally, I offer some concluding remarks in Section 7.4.

7.1 Revisiting (and answering) the research questions

The case study of Mrs. Miller consists of a systematic analysis of a teacher's instructional practice as she implemented an inquiry-based curricular module in three successive academic years. This research was guided by two overarching research questions, originally presented in Section 1.4. These questions are reprinted here for the reader's reference:

Within the context of endeavoring to teach science as inquiry in the classroom:

(1) How can a teacher's responsiveness to student thinking be characterized?

(2) How does one teacher, Mrs. Miller, change with respect to her responsiveness to student thinking over the course of three iterations of an inquiry-based module?

The first of these two questions is methodological in nature and was designed to help fill a gap in the research literature by identifying one or more methods capable of characterizing a teacher's responsiveness to her students' thinking. The second of these questions builds upon the answer(s) to the first by using the identified method(s) to describe a teacher's change in responsiveness over an extended period of time (i.e. three iterations of an inquiry-based module of the water cycle).

Answering the first research question

The primary objective of this study was to characterize changes in one specific aspect of Mrs. Miller's instructional practice: her responsiveness to student thinking. Ultimately, two methods of analysis enabled me to effectively capture elements of this dimension of Mrs. Miller's practice, each with its own affordances and limitations. These are reviewed here briefly.

Method 1: Characterize the teacher's redirections

A close examination of Mrs. Miller's classroom discourse resulted in the identification of the "redirection," an instructional move where the teacher (Mrs. Miller in this case) issued a bid to shift or "redirect" her students' attention from one locus or activity to another. Mrs. Miller's practice of issuing redirections was a distinct instructional move (evident through discourse analysis) that could be characterized in terms of varying levels of responsiveness. Thus, one method to characterize a teacher's practice of responding to her students' thinking is to identify and code his or her redirections. Such a method enables researchers to employ both quantitative *and* qualitative methods to analyzing teachers' instructional practice.

Method 2: Describe the teacher's practice phenomenologically

While the first method of analysis is, arguably, effective in describing a teacher's responsiveness to her students' thinking, it is rather narrow in focus; such a method relies primarily on an examination of those talk turns that constitute redirections. Analyzing Mrs. Miller's instructional practice phenomenologically had the capability of capturing additional facets of Mrs. Miller's responsiveness, potentially compensating for limitations of the first analysis method. The phenomenological method applied a broader lens to Mrs. Miller's practice and resulted in descriptions of instructional elements that reflected responsiveness as enacted during two recurring events. Although it would not necessarily be feasible to adopt this approach for the entirety of a comprehensive data set, a comparison of Mrs. Miller's practice across a few specific events illuminated aspects of her responsiveness. Such a method of analysis enabled me to extend the findings from the analysis of Mrs. Miller's redirections.

Answering the second research question

The second research question concerned *how* a teacher's responsiveness to student thinking changed over time. Applications of the two methods of analysis identified in the previous subsection afforded the means to answer this question.

Capturing teacher change via method 1: Characterizing Mrs. Miller's redirections

A simple quantitative analysis of Mrs. Miller's redirections showed that Mrs. Miller did indeed change with respect to the total number and the types of redirections issued across the three implementations (see Table 5.1). However, this change, as reflected by the quantitative results, did not appear to be smooth or linear. For example, Mrs. Miller's total number of redirections decreased during Implementation 2 and rose considerably during Implementation 3. In addition, Mrs. Miller issued the lowest frequency of redirections that were *minimally* connected to student thinking in Implementation 2 and the highest frequency of these redirections during Implementation 3. Such results are somewhat ambiguous and can possibly be interpreted as Mrs. Miller having *decreased* in her responsiveness over the course of the three implementations.

A closer examination of Mrs. Miller's use of highly responsive redirections (e.g. FC1 CON, FC1 MOR, AC1) seemed to tell a slightly different story, however. Whereas Mrs. Miller issued fewer total redirections in Implementation 2, the highly responsive redirections that she *did* issue seemed to help perpetuate and prolong the lifetime of potentially productive student ideas. This was in contrast to Implementation 1, where despite issuing a greater number of redirections, Mrs. Miller seemed to have a relatively higher number of "missed opportunities." There seemed to be more occasions where Mrs. Miller did not follow up productive student ideas with redirections and/or Mrs. Miller allowed students to shift their attention away from potentially rich ideas without elaborating or pursuing them in Implementation 1.

During the third implementation, Mrs. Miller again issued a high number of redirections. This time, consistent with observations in Implementation 2, her highly responsive redirections seemed to regularly help perpetuate and prolong rich student ideas. Additionally, Mrs. Miller seemed to have fewer "missed opportunities" than in *either* of the previous two implementations. Thus, analyses of Mrs. Miller's use of highly responsive redirections (i.e. when and how she issues them) seemed to indicate that Mrs. Miller *increased* in her responsiveness to her students' thinking over the course of the three module implementations.

Capturing change via method 2: Describing Mrs. Miller's practice phenomenologically

An adoption of a phenomenological approach when examining Mrs. Miller's instructional practice highlights two important changes across the three implementations, both of which suggested an increased level of responsiveness to her students' thinking. First, Mrs. Miller seemed to be more accepting of students' "alternative" explanations (i.e. explanations different than those which are believed to be scientifically accurate) in the second and third implementations. She not only was more willing to have her students express well-reasoned alternative explanations, she seemed to actively encourage her students' development and elaboration of these explanations. Second, Mrs. Miller seemed to allow her students' ideas, questions, and explanations to *inform* the direction of the class much more in later implementations, and especially during Implementation 3. Mrs. Miller appeared to utilize student comments both as a foundation for additional activity *in-the-moment* (i.e. during instruction) and to initiate activity at some later point (i.e. during a future class session).

Synthesizing the findings and answering the research question

Both methods of analysis provided evidence to support a claim of an *increase* in Mrs. Miller's responsiveness over the course of the three implementations. The redirection analysis showed that Mrs. Miller was more likely to hear, take up, and nourish her students' potentially productive ideas in later implementations. The phenomenological analysis showed that in later implementations Mrs. Miller was more likely to: (1) encourage students to entertain and develop alternative explanations and, (2) utilize student ideas as the basis for additional discussion and activity. Thus, it appears as if Mrs. Miller *did* change over the course of three iterations of an inquiry-based module, specifically by increasing in her level of responsiveness to her students' thinking.

7.2 Strengths of this study and contributions to the field

Strengths

There are several strengths to this work. First, previous studies of teacher change *in situ* have generally restricted analyses to relatively short time intervals (i.e. two academic years or less). No studies investigating teachers' change in instructional practice have included teacher observations that have extended beyond two academic years. Additionally, previous studies have generally involved fewer than five teacher observations, in some cases relying on as few as two observations to make claims of teacher change (e.g. Blanchard et al., 2009; Sherin & van Es, 2009). The current case study analyzes a teacher's instructional practice across *three* iterations of an inquiry-based module, occurring over three successive academic years. It is grounded in the analysis of *numerous* classroom observations over the entire implementation span (i.e. forty-three class sessions in total). Thus, this study presents findings from a rigorous examination of a teacher's instructional practice that took place over an extended period of time.

Second, there have been, as yet, few methods of analysis capable of capturing the nuances of the process of a teacher's change in instructional practice. The current study isolates and defines a specific aspect of a teacher's instructional practice (the redirection) and describes a method by which this aspect can be used to characterize teacher change. Thus, this study presents a means by which researchers can characterize an element of a teacher's practice (specifically one that reflects his or her responsiveness to student thinking) and use that element to describe his or her change over time.

Third, the redirection is an analysis construct that affords a means for educational researchers to code teacher utterances according to the level and nature of the teacher's responsiveness to his or her student's thinking. To date, researchers interested in examining teachers' practice of attending and responding to student thinking in the classroom have tended to ground their claims on qualitative content analysis of teacher discourse (e.g. Levin, 2008, Levin et al., 2009; Pierson, 2008, Sherin and van Es, 2009). By coding teachers' redirections, researchers are afforded a means to conduct quantitative analyses, in addition to those of a qualitative nature.

Finally, this research study did not rely on a single method of analysis to make claims about a teacher's change in instructional practice. Instead, two methods of analysis were utilized, the first using a narrow lens by which to examine the entire data set for evidence of change, the second using a broad lens by which to examine a subset of the data for evidence of change. These methods of analysis, while different from one another, complemented each other and allowed for a richer and more comprehensive description of Mrs. Miller's change in practice.

Contributions

There are several contributions that this research offers the educational research community. First, this research makes an important empirical contribution. Teaching science as inquiry has received much attention in the past few decades (NRC, 1996; 2000; 2007). This work provides considerable evidence that an experienced teacher *does* change in her instructional practice as she enacts a flexible, inquiry-based module over time. This case study provides a rich and comprehensive description of how Mrs. Miller increasingly made room for and took up her students' thinking over the course of three module implementations, as evident through the extensive analyses of her classroom practice.

Methodologically, there are several additional contributions of this work to the field of mathematics and science education research. First, this study presents an example of how an *extended* interval of successive classroom observations (e.g. daily observations during three implementations of a curricular module) can be used to make claims about teacher change. Secondly, this research describes a new means to isolate and characterize a specific aspect of a teacher's instructional practice (the "redirection"), one that reflects the degree to which the teacher takes up his or her students' thinking. Third, the redirection analysis (i.e. Method #1) provides one example of how a *mixed methods* approach (i.e. an analysis method that utilizes quantitative and qualitative elements) can serve to elaborate and extend the findings of either method alone. Finally, this research study exemplifies how two different yet complementary approaches to analysis (one narrow, one broad) can arguably yield more comprehensive results and potentially provide a more solid foundation for claims of teacher change.

Finally, while the construct of the "redirection" was originally conceptualized as an analysis tool to afford researchers a means to characterize an aspect of teachers' instructional practice, it is conceivable that such a construct could be used in teacher training.

In the classroom, educators are faced with myriad emergent situations, such as students posing unexpected questions and students not grasping a seemingly simple concept. As such, teacher decision-making *during* instruction is viewed as a critical component of teacher practice (Clark & Peterson, 1986). When presented with classroom events requiring on-the-fly decisions, teachers may opt to: (1) do "nothing" at that time, (2) probe a student for more information, or (3) shift students' attention to another locus (Clark & Peterson, 1986; Clough, Berg, & Olson, 2009; Schoenfeld, 1998; 2008). Teacher beliefs, goals, and knowledge are all believed to play a role in determining *how* the teacher ultimately decides to act in these moments (Schoenfeld, 1998; 2008).

Redirection "awareness" may represent an additional knowledge element that could serve to inform the interactive teacher decision-making process. If teachers are exposed to the different types of redirections, including those of "higher" degrees of responsiveness (e.g. AC1, FC1 CON, FC1 MOR) and "lower" degrees of responsiveness (e.g. AC2, FC3) for example, such knowledge could help teachers to be more conscious of the options open to them during the decision-making process. The results of this knowledge could be that teachers are more deliberate in taking up and exploring student questions or comments (both anticipated and unexpected) as they emerge during class discussions.

7.3 Limitations of this work and areas for future study

As with any research study, there are several limitations to this work. Many of these limitations highlight areas for future study. Hence, these two topics will be taken up together.

First, since this study focuses on *one* teacher's change in instructional practice, it is questionable whether the findings described here are common among veteran elementary teachers and/or generalizable to other teacher populations (e.g. pre-service elementary teachers, secondary teachers). While the methods of data collection and analysis used in this study limit the feasibility of analyzing the practice of a large number of teachers, the question of generalizability is worthy of attention. Thus, an area of future work is to examine the instructional practice of additional teachers to explore how other teachers change, and whether they change in a manner similar to Mrs. Miller. It would be interesting to explore which aspects of Mrs. Miller's change are unique to her and which are common to other teachers.

Second, the instructional practice of responding to student thinking seemed to be an appropriate locus for research, since it is considered to be an important component of teaching science as inquiry (Levin et al., 2009; NRC, 2007). However, it is only one dimension of a teacher's instructional practice. Thus, this study is limited in terms of facets of a teacher's practice examined. There are arguably other dimensions of a teacher's instructional practice associated with inquiry instruction (NRC, 1996, 2000) that might prove to be useful elements for analysis (e.g. teachers' questioning strategies, teachers' moves to engage students in cooperative learning activities, teachers' moves to engage students in their own empirical investigations). A future research direction might involve subjecting Mrs. Miller's classroom data, in part or in entirety, to analyses aligned with one or more of these other dimensions of her practice. It is possible that such analyses could paint a very different picture of Mrs. Miller's change.

Finally, this study restricted analyses to only the segments of classroom activity that consisted of *whole class discussion*. Observations of Mrs. Miller's interactions with her students during small group activities suggest that her behavior (inclusive of her talk and co-occurring non-verbal body language) differed from that during whole class activities. In particular, Mrs. Miller's dialogue concerning *content* (e.g. scientifically accurate explanations vs. inaccurate explanations) with her students seems to change when she shifted from whole class to small group. Thus, an area of future work might explore differences in Mrs. Miller's instructional practice as she engaged with students in whole class, in small groups, and during individual work.

Other areas worthy of future attention

In addition to the areas described above, there are two other avenues that warrant consideration for future research studies. First, the purpose of this study was to characterize Mrs. Miller's change over the course of the three module implementations. One natural extension of this work would be to attempt to *account* for this change. Others have argued that shifts in teachers' beliefs and/or attitudes towards teaching and learning in their discipline can result in changes in their instructional practice (e.g. Blanchard et al., 2009; Schoenfeld, 1998). Thus, it is conceivable that changes in Mrs. Miller's beliefs about science and/or science learning were responsible, at least in part, for the changes described in this work. With the extensive video data accumulated by the

Learning Progressions for Scientific Inquiry (LP) project (e.g. debriefing interviews, one-on-one interviews, professional development sessions), it may be possible to explore whether shifts in Mrs. Miller's attributable beliefs may correspond to the shifts in what was observed in class during the module implementations. Others have begun to examine how teachers' changes documented during professional development parallel their changes displayed during classroom activity (Sherin & van Es, 2009). Future examination of Mrs. Miller's comments and/or activity during the professional development sessions might make it possible to expand upon this previous work.

Another area for future research is an exploration of what it means to establish reliability for contextually bound content material. As discussed in Section 4.5, the predominant challenges faced during the process of establishing inter-rater reliability concerned the issue of context. While it was relatively easy for the coders to consistently identify Mrs. Miller's talk turns as redirections and further characterize those utterances as focus or activity redirections, it was much more challenging for coders to agree on the *type* of activity or focus redirection a talk turn represented. Since this research focused on a teacher's responsiveness to her students' thinking, context necessarily played a large role in determining the specific codes assigned to Mrs. Miller's utterances (e.g. *To what* is Mrs. Miller responding? *How* is Mrs. Miller responding?). Such contextually driven content analysis might demand different rules when establishing validity and reliability. At the very least, the issue of reliability certainly warrants further consideration.

7.4 Concluding remarks

I conclude this document by revisiting the current emphasis placed on teaching science as inquiry. While not a new area for science education, inquiry's current inclusion on national and state standards (California Department of Education, 2000; NRC, 1996, 2000, 2007) has prompted many educators, policy makers, curriculum developers, and educational researchers to reconsider how to best teach inquiry in the science classroom. The Learning Progressions for Scientific Inquiry (LP) project, the larger project from which this study emerged, took the perspective that inquiry is "a pursuit of coherent, mechanistic accounts of phenomena" (Hammer et al., 2008, p. 150). To support this pursuit, the LP project designed opportunities for teachers and their students to engage in consideration, discussion, and investigation of natural phenomena. The flexible, open-ended water cycle module afforded Mrs. Miller a context in which to engage her students in consideration of natural phenomena. The module did not dictate what topics to cover; rather, it allowed her space to elicit her students' ideas about different phenomena related to the water cycle and utilize those students' ideas as a foundation for further discussion and/or activity.

This research study demonstrated that over the course of three iterations of implementing the inquiry-based module, Mrs. Miller grew in her responsiveness to her students' thinking. Mrs. Miller increased in her tendency to allow her students to entertain well-reasoned alternative scientific explanations. She was more likely to allow her students' ideas to inform the direction of the class. Finally, Mrs. Miller was more likely to take up her students' ideas and help nourish the elaboration and development of those ideas by inviting others in the class to consider and discuss those ideas. Such findings support a claim that Mrs. Miller grew in her ability to teach inquiry, both as it is conceived by the LP project and, more broadly, as it is outlined in the NSES (1996). I believe that Mrs. Miller's evolution in teaching science as inquiry provides other researchers and professional educators with a wonderful example of how teachers can incorporate novel and/or reform-based pedagogy in the classroom.

ENDNOTES

[1] The “Learning Progressions for Scientific Inquiry project” or “LP” is the shortened name of the NSF funded project (#0732233) officially entitled, “Learning Progressions for Scientific Inquiry: A Model Implementation in the Context of Energy.”

[2] This conceptualization of a “responsive” curriculum differs from that of other curricular developers. Rather than refer to curricula designed to be responsive to a specific group (e.g. culturally responsive curricula) or those with a specific need (e.g. emotionally responsive curricula), our use of “responsive” in this case pertains specifically to curricula designed to allow the teacher to be *responsive* to the ideas of her students as they emerge during instruction.

[3] All teacher and student names presented in this document are pseudonyms.

[4] This statement is made on the basis of Mrs. Miller’s self-reports and field observations of her teaching non-module science lessons.

[5] By “substance” of a student’s idea, I am specifically referring to the meaning or *sense* (Levin, Coffey, & Hammer, 2009) behind the idea, not just the terminology that he or she might be using in their elocution.

[6] The five phases of the 5E learning model (engage, explore, explain, elaborate, and evaluate) comprise a method of instruction designed to help students build and extend their prior knowledge over time through active participation in the learning process (Lawson, 2010; National Institute on Drug Abuse [NIDA], 2000).

[7]The BSCS continues to generate biology textbooks and other curricular resources to this day.

[8] By "merit" of a student idea, I specifically refer to the instructional merit of a student's idea. This includes, but is not restricted to, how consistent the student's idea is to the scientifically accepted answer. The idea's merit can also be measured in terms of how well reasoned the particular idea is (e.g. is the idea consistent with the student's past experiences and/or instruction) and/or if that idea provides rich grounds for consideration and debate within the class community.

[9]There are researchers that disagree with this developmental stage approach. For example, Levin, Coffey, & Hammer (2009) suggest that many novice teachers are capable of attending to their students' thinking early in their development.

[10] The first skill of attending is distinct from the skill of selective attention as described by Sherin and van Es (2009) with respect to the locus of attention. Sherin and van Es examined the *types* of events to which teachers selectively attended. In contrast, Jacobs et al. (2010) provided the teachers with a specific event: children's thinking. They instead examined to what details of the provided event teachers attended.

[11]The phrase "classroom discourse" goes beyond the talk between members of the classroom community. My conceptualization of discourse and the analysis thereof is more aligned with Gee's (2005) definition of capital "D" discourse, which encompasses the language, actions, and interactions of the various participants, as well as the manner in which they use and generate artifacts (e.g. tools, symbols, and other objects).

[12] The phrasing of this question is consistent with that as posed to Mrs. Miller's students on Day 1 of Implementations 1 and 2. The phrasing of this question was altered slightly on Day 1 of Implementation 3. See Section 6.2 for the exact phrasing.

[13] Video permission had previously obtained for each student in the class.

[14] The focus redirections that were assigned the “repeat” (REP) code were *not* included in the chi square analysis, due to the fact that no examples of this code were found in the second implementation.

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