Interpreting Elementary Science Teacher Responsiveness Through Epistemological Framing

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In this study we build on the closely related constructs of teacher attention and responsiveness to explore how one fifth-grade teacher facilitates scientific inquiry. We illustrate the dual use of responsiveness and framing through the case study of Mrs. Charles, who skillfully elicits and builds on students' ideas in her science classroom. In our analysis, we found that ranking the extent of this teacher's responsiveness was inadequate for describing the nature of her teaching and for uncovering ways in which this teacher might progress. Analyzing Mrs. Charles's practice in terms of her framing of the situation, however, began to reveal patterns and nuances in the nature of her responsiveness. We argue that it is through the overlay of her epistemological framing onto an analysis of her responsiveness that we get a fuller picture of Mrs. Charles's practice: inviting and valuing students' contributions while encouraging exploration of certain ideas over others.

Introduction

Reform in science education calls for active student engagement in scientific inquiry (NRC, 1996), where children propose, evaluate, investigate, and synthesize ideas to develop causal explanations of phenomena (Duschl Schweingruber & Shouse, 2007). While research has documented that children have abundant nascent resources for reasoning about and making sense of the world around them (diSessa, 1993; Metz, 1995; Tytler & Peterson, 2004), transforming these abilities into expertise in scientific inquiry still requires substantial work, both for the learner and for the teacher. Students must engage extensively and productively in practices like reasoning mechanistically (Russ, Scherr, Hammer & Mikeska, 2008), modeling (Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Shwartz, Hug & Krajcik, 2009), and seeking coherence among ideas (Sikorski, Winters & Hammer, 2009). If students' own ideas and reasoning are to serve as the building blocks for both the process of scientific inquiry and the scientific understandings that constitute the products of inquiry, instruction cannot be scripted or prepackaged (Duschl et al., 2007). Instead, the teacher has the responsibility to elicit, interpret, and follow up on students' reasoning in the moment, in a fashion that values students' ideas as objects of inquiry (Cohen, 2004).

The teacher's role in facilitating scientific inquiry is quite different from what her role would be in a traditional science classroom. Listening and attending to the sense students are making, rather than focusing primarily on how their responses align with scientific canon, requires not only a shift in how the teacher conceptualizes her role in the classroom (Empson and Jacobs, 2008), but contrasts with the social and institutional objectives to which teachers are held accountable (Levin, 2008). Additionally, children frequently have difficulty articulating their thinking, and therefore it requires a teacher's focused attention and effort to interpret student meaning (Sherin & van Es, 2009). The closely related constructs of noticing and responsiveness have emerged in the mathematics education literature as a means of describing what it is teachers attend to in students' thinking and what it is they pursue in their follow-up moves (Empson & Jacobs, 2008; Franke, Carpenter, Levi, & Fennema, 2001; Pierson, 2008; Sherin & van Es, 2009). This literature analyzes teachers' actions as they progress to higher levels of noticing and attending to children's mathematical ideas, emphasizing *what* the teacher responds to without an intentional focus on *why* a teacher might be attending to certain ideas over others. Understanding why a teacher notices or responds to specific ideas or in specific ways can inform efforts to promote teacher change.

In this preliminary study, we explore how to account for the 'what' of a teacher's responsiveness in terms of a possible 'why'—the teacher's framing of the situation. We exemplify how a teacher's facilitation of scientific inquiry can be described in terms of the relationship between her responsiveness and framing, and illustrate this with a case study of one fifth-grade teacher embarking on pedagogical change.

Framing of the Classroom Activity

Teachers have a tacit understanding of what it means for their students to "do science" that shapes what it is they attempt to enact in their classrooms. A person's answer to the question, "What is it that's going on here?" is what we refer to as his or her *framing* of the situation (Goffman, 1986; Hammer, Elby, Scherr & Redish, 2005; Tannen, 1993). With respect to elementary science, there are many possibilities for how a teacher might answer this question. For example, "doing science" in the classroom may involve reading the textbook, following prescribed experiments, or engaging in debates about natural phenomena. Consistent with Hammer, Russ, Mikeska, and Scherr's (2008) definition of scientific inquiry, we hope teachers will come to see classroom science as the *pursuit of plausible, mechanistic accounts of natural phenomena*.

The theoretical construct of framing, as we use it here, is distinct from but related to a more colloquial use of "framing" as one's intentional portrayal of a situation to others. When we describe how a teacher frames the classroom activity, we are referring to her own perception of the situation rather than to how she deliberately represents a task for her students. For us, the power of framing lies in its ability to describe a person's implicit understanding of the nature of the broader situation she finds herself in. In this sense, we consider framing at a comparatively large grain size. There are multiple aspects to any given framing: social interactions, tool use, and body language, as well as what it means to "know" something in science, that is, the *epistemological* nature of the scientific endeavor. This component of framing differs from epistemological beliefs in that framing accounts for what the teacher does in the classroom, that is, her actions and the roles she takes on while teaching science. This does not always coincide with her explicitly stated, decontextualized views about teaching and the nature of science (Abd-El-Khalick, Bell & Lederman, 1998; Lederman, 1999).

In cases where framing has been used to describe how students reason about science, there is evidence to suggest that their framing constrains both the types of knowledge they employ and how they use that knowledge (Hammer, et al., 2005; Louca, Elby, Hammer & Kagey, 2004). We take this as an indication that a teacher's framing could describe the lens through which she attends to student thinking. This may elucidate how and why she is responsive to certain ideas over others, and how she uses these ideas in her response.

Responsiveness to Student Thinking

Previous work in mathematics education suggests that how a teacher listens can transform how children talk and, ultimately, influence what they learn (Jacobs, Lamb, Philipp, & Schappelle, 2009; Sherin & van Es, 2009). When studying teachers participating in video-based professional development, researchers found that what teachers attend to—what they notice about the mathematical details of the child's idea—is intertwined with how they respond to students (Empson & Jacobs, 2008; Jacobs, et al., 2009). Classroom studies of teacher noticing use moment-by-moment statements of students and teachers as the units of analysis (Pierson, 2008; Sherin & van Es, 2009). For example, Sherin and van Es (2009) focused on instances when student ideas were presented in class and then determined whether or not teachers noticed these ideas. Pierson (2008) quantified patterns in teachers' follow-up utterances in whole class discussions to characterize a teacher's responsiveness, which she defines as "the extent to which teachers 'take up' students' thinking and focus on student ideas in their moment-to-moment interactions" in the classroom (p.25). Pierson found a significant correlation between student learning and the highest level of teacher responsiveness that she articulates (High II). In defining High II responsiveness, Pierson identifies four types of teacher follow-up moves: an invitation to further explain the idea, offering a contradiction or counterclaim related to the idea, an invitation for other students to make sense of the idea (agree/disagree, etc.), or uptake of the student's idea through revoicing or expanding the reasoning. In our work, we acknowledge the dynamic relationship between attention to students' ideas and responsiveness, and we examine how a teacher responds in order to infer what she is noticing about a student's ideas.

When accounting for the actions of an experienced teacher implementing a module in scientific inquiry, we found that utterances and follow-up questions provided too small of an analytic grain size to adequately make sense of *why* the teacher was choosing to respond in a particular way to students' ideas. Our purpose in this paper, therefore, is to argue that it is more useful to characterize a teacher's progress in promoting scientific inquiry in terms of *both* responsiveness and framing. In our analysis, we aim to show how a teacher's own framing of scientific inquiry influences how she hears and responds to students' ideas.

Methodology

This study is part of a larger NSF-funded project to, in part, identify what constitutes teachers' progression in their abilities to facilitate scientific inquiry (1). During the first year of professional development, practicing third-through sixth-grade teachers from a large school district in southern California attended a one-week summer workshop in August 2008, and biweekly teacher meetings during the 2008-2009 school year. During these sessions, teachers participated in (a) "science-talks" designed to model what scientific inquiry is, and (b) discussions of classroom video, often taken from their own classrooms, where children's scientific reasoning is on display. We expected that many of the teachers would not initially focus closely on the substance of student reasoning for the reasons described in the introduction. We found, however, that a few teachers did in fact attend to students' ideas in ways that existing measures of responsiveness would categorize as high. For this paper, we focus on one of the latter teachers, Mrs. Charles (pseudonym), and describe how we identified what might constitute progress for her in promoting scientific inquiry in her classroom.

The data sources for this study include video recordings of Mrs. Charles's implementation of a 15-hour module. On the first day of the module, the supporting curricular materials suggest that teachers pose the following question to their students:

> Suppose that one night it rains. When you arrive 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?

Rather than follow a scripted curriculum, teachers were encouraged to pursue ideas and questions which students brought up during the discussion of this first question. Additional data included classroom field notes taken by the second author, and video and/or field notes from debriefing sessions with the second author after each day's instruction.

Analysis proceeded in phases. Initially both authors independently viewed all of the classroom video, identifying instances when Mrs. Charles was responsive to students' ideas that were raised in class. We use responsiveness in a broad sense to mean noticing and responding to a student's idea either by rephrasing the idea, probing for further clarification, or shifting the direction of the discussion in a way that addresses the idea (Levin, Hammer, & Coffey, 2009). Finding that Mrs. Charles was generally responsive to students' ideas, each author then identified and transcribed several episodes representing the various types of activities in the classroom (small group discussion, small group experimentation, whole class discussion). Analytic memos summarizing the student ideas and interpreting Mrs. Charles's responses within these episodes were compared by the two authors to try to understand the nature of Mrs. Charles's responsiveness. By means of the cyclical, interpretive analysis cycle (Clement, 2000) (2), we continued to analyze video episodes and modify our account of Mrs. Charles's responsiveness until we found a pattern that fit the data and presented a reasonable, coherent account of her actions. We argue below that it was only by applying the construct of framing to our analysis of Mrs. Charles's actions that we were able to understand why she consistently responded in particular ways to students' ideas. The coupled use of these constructs—responsiveness and framing—is the main focus of this preliminary work, and we save for future analysis the endeavor of quantifying the frequency with which Mrs. Charles frames science in any given way.

Findings

Mrs. Charles took very quickly to the practice of giving students space to express their ideas. From the initial opening question about a puddle, Mrs. Charles facilitated discussions and encouraged experimentation based on the questions students posed about various topics related to evaporation. For example, after listing on the board several student-generated questions, Mrs. Charles asked: "What do you think that we should explore up there [on the board], that we've been talking about today? And how do you think we should explore it? What do you think we should do?" Students' ideas were welcomed, made public, discussed, and clarified so that they could become objects of inquiry for experimentation. The following segment of transcript, taken from a student-initiated class debate, exemplifies how Mrs. Charles provides space for students to describe their own reasoning and critique others' ideas.

Mrs. Charles:	What do you think?! Susan.
Susan:	Um, when you were reading it (…) um, the size of the parking lot. I don't think that would affect it, because you're talking about a puddle, which is not, like you're not measuring [pause]
Mrs. Charles:	Talk to this table. They were the ones who put it on. I have nothing to do with it. I just read it. [To Cody:] Go.
Cody:	Well, um. Well, the heat comes down on the parking lot, 'cause the parking lot is really big, then the heat won't go to that one little water spot. It will go to everywhere, and it won't be hot in that water spot. If it's smaller, it will focus in on that, on a littler spot, and it'll be hotter.
...	[1 min and 40 sec of debate between Cody and Susan]
Mrs. Charles:	Andrea, did you want to add something to it?
Andrea:	It actually does matter, because, um, if the parking lot's bigger, the sun would go everywhere in the parking lot, and it wouldn't be as hot in that one area where the

	puddle is. And if it's smaller, it would be hotter because it's a smaller area and more heat would be able to go in there, in that one area.
Mrs. Charles:	Brian, you're shaking your head. What's going on?
Brian:	Wouldn't the sun go to every single place?
Susan:	Yeah, but that's what I was doing.
Cody:	Yeah, but it wouldn't be as hot, 'cause it has to cover all those places.

This episode is representative of Mrs. Charles's interactions throughout the module in that she facilitates discussions between students, allowing their reasoning to develop in response to critiques from classmates rather than looking to an authority figure for approval or disapproval. Mrs. Charles promoted experimentation—not the assertion of a teacher or text—as the ultimate authority on "what worked", and often led student discussions toward empirical investigation. During the module, Mrs. Charles guided her class in four cycles of exploration, each consisting of students (a) generating a variety of questions while discussing some aspect of the puddle, (b) selecting which questions to pursue, (c) designing and implementing experiments to test those ideas, (d) reporting outcomes, and (e) finding new questions and topics of investigation. Each cycle lasted approximately 2-4 hours spread over one to two class periods, and students spent a considerable portion of this time engaged in experimenting. This overall organization of the module emerged from Mrs. Charles rather than from professional development or project directives and was driven more by students' ideas than most other teachers' module implementations were during this first year of the project.

Analyzing Mrs. Charles's classes, we find evidence of her responsiveness to student thinking. She consistently responds to students by restating the idea or asking others what they think of the idea without "taking over" the students' thinking. This, according to the literature, is evidence of attention to students' ideas (Empson & Jacobs, 2009; Pierson, 2008; Sherin & van Es, 2009). A closer analysis of extended episodes, however, revealed a consistency underlying Mrs. Charles's responsiveness, a consistency arising from what we suspect to be a relatively stable framing of what science class is all about.

Framing Influencing Responsiveness

Mrs. Charles's frequent attention to one specific aspect of students' ideas, the potential testability of an idea, is what caused us to question the sufficiency of analyzing Mrs. Charles through the lens of her responsiveness alone. This section provides two extended examples of Mrs. Charles being responsive to her students in a way that promotes science as a fundamentally empirical endeavor. These episodes, although representative of the typical teacher-student interactions in her classroom, were chosen because they effectively portray the nuances of what aspects of student thinking Mrs. Charles notices and responds to, and to what ends she uses these ideas.

Example 1

While interacting with small groups, Mrs. Charles frequently steers students to consider further experimentation. Just prior to the following episode, Mrs. Charles had asked the whole class to draw what they saw happening to the puddle during their experiments on the previous day. While visiting a small group, she elicits one student's thinking, challenges the epistemological basis of his claim, and then poses a question that both answers that epistemological challenge and suggests a course of action for the students:

Mrs. Charles:	Okay, so what is it you have there [on your drawing]?
Matt:	Okay. So the heat goes, like, down into the water. And then the water turns into its gashus or gas-e-ous [laughs]--its-its-its gas form--which is called water vapor. And so, like, this is what's happening.
Mrs. Charles:	How do you know that it's the heat from the sun that's causing it, and not the heat from the ground?
Matt:	Well, it could be the heat from the ground, but the ground got heated up from the sun. So it's originally from-from heat, right?
Mrs. Charles:	[to boy sitting next to Matt] So wha'd'ya think? Do you agree with him?
Matt:	'Cause the ground got heat from the sun, and the sun. So it's like both.
Mrs. Charles:	How would you test that to prove it?

Mrs. Charles displays responsiveness throughout this interaction by eliciting ideas, engaging with the specifics of a student's idea, challenging the student's thinking without promoting her own reasoning as a substitute, and inviting others to make sense of that student's idea. Upon closer inspection, we find that Mrs. Charles's responsiveness is focused primarily on the aspects of Matt's idea that lend themselves to empirical investigation.

Matt's response to Mrs. Charles's initial elicitation describes a causal chain of events that begins to account for what happens to the puddle: heat from the sun goes down to the water, which then causes the water to change into its gas form. Mrs. Charles follows up with a responsive, substantive probe ("How do you know … ?") about one specific aspect of Matt's reasoning—that the heat affecting the water comes "down" from the sun. Mrs. Charles's question could be a way of asking Matt to expound on his mechanistic understanding, and perhaps she has reason to believe that the nature of the heat source is vital to his budding model. Her subsequent follow-ups, however, do not continue to press for explanation. Rather, her final comment ("How would you test that to prove it?") is a clear invitation to design an experiment.

The aspect of Matt's reasoning that Mrs. Charles chooses to focus on—where the source of the heat comes from—is perhaps the most practical component of Matt's explanation to investigate empirically. Identifying the source of the heat translates nicely, although not simply, into experimental treatments, where the "ground" surface temperature is controlled, and where a fixed amount of light can reach the puddle. However, a direct empirical investigation of the process Matt alludes to, of how "the water turns into its ... gas form", is not nearly as straightforward. In this sense, Mrs. Charles's highlighting of "heat goes, like, down into the water" rather than "the water turns into its ... gas form" is consistent with a framing of scientific inquiry as fundamentally about developing questions and conducting experiments to answer those questions.

Example 2

This second example is taken from a group of students in the midst of a controversy: one student is adamant the "stuff" they observed rising off their puddle was heat, and the others insist that it was water vapor. As before, Mrs. Charles elicits students' ideas and follows up on the content of those ideas, and she probes with an epistemological question as opposed to responding to the main point of contention.

Mrs. Charles:	K, wha'd'you guys think?
Susan:	*She* [Ella] thinks it's water.
Ella:	*She* [Susan] thinks it's not water vapor. And then, we think that it *is* water vapor, but then she's gonna raise her hand, say her opinion and stuff-
Mrs. Charles:	[to Susan] Why do you think it's not water vapor?
Susan:	Because-
Mrs. Charles:	What do you think it is?
Susan:	Um, I think it's heat because the blacktop is, like, really, like, hot?
Mrs. Charles:	Mmm hmm
Susan:	And if you put a puddle on it, it's, like, gonna, like, react? to it?
Mrs. Charles:	Okay.
Susan:	And so, I think what's coming up is, like, heat.
Mrs. Charles:	How do you know that if you put a puddle on something hot it's gonna react to it?

Again, Mrs. Charles displays responsiveness to student thinking in that she elicits student ideas, acknowledges ideas, highlights specific elements of an idea, and challenges the student to support her claim. Even when Ella is reflecting on the nature and ramifications of the group's disagreement, Mrs. Charles chooses to be responsive to the scientific substance of the student's thinking, asking Susan what she thinks the "stuff" is. What is interesting is that Mrs. Charles follows up by probing how Susan would know something would react, as opposed to choosing to pursue the idea under debate, that is, whether the "stuff" is heat or water vapor.

As Mrs. Charles leaves this group, she reinforces that she wants the students to devise an experiment. While the group continues to debate, one member directly asks Mrs. Charles what that "stuff" rising off the puddle is. She responds by saying, "I don't know. What d'you think, and how can we prove what we're thinking?" Here the topic of the implied experiment is central to the controversy: what that "stuff" is. Mrs. Charles asks the student what he thinks the "stuff" is, but instead of asking *why* he thinks that, she focuses on how he could prove what the "stuff" is. Nominating this idea for experimentation provides further evidence of this nuanced aspect of her responsiveness.

Framing as a way to understand a pattern in Mrs. Charles's Responsiveness

How do we account for the nature of Mrs. Charles' responsiveness and consider what progress for her might look like? In the analyses above, we exemplify how Mrs. Charles seems to attend to one specific aspect of students' ideas—their potential for empirical exploration. We suggest that, in general, interpreting a teacher's actions in terms of her framing of science can elucidate *what* she is responsive to and *how* she is responsive. In the case of Mrs. Charles, this analysis finds her responsiveness taking the form of guiding students towards experimentation as a way to "prove" their thinking. The component of Mrs. Charles's framing that is most relevant here has to do with her stance on how students go about constructing scientific knowledge, which we will refer to as her *epistemological* framing (Hammer, et al., 2005). Along with the consistent nature of her responsiveness to ideas that are testable, additional sources of data (comments about her class during debriefing sessions and the iterative exploration cycles during the module) provide further evidence to suggest that Mrs. Charles frames the inquiry module as an opportunity to pose critical questions about phenomena and investigate them empirically.

The epistemological component of Mrs. Charles's framing treats knowledge as inherently empirical: we have ideas in science, but we have to test them to know if they are correct. This captures an important component of the nature of science: that science is accountable to empirical findings (Abd-El-Khalick & Lederman, 2000; McComas, 1998). Experimentation, however, is only one part of inquiry. Many teachers' conceptualizations of inquiry involve setting up experiments and identifying the observable outcomes, but do not involve the development of theories or models of natural phenomena (Chinn & Malhotra, 2002; Windschitl, 2004). Therefore, teachers' ideas of what science *is* may require subtle, but important changes.

Although the students' ideas and questions provide the terrain for exploration in Mrs. Charles's class, a desirable and sophisticated inquiry practice, we found that her consistent epistemological framing of science inquiry as primarily empirical investigation also resulted in less desirable aspects of classroom science. For example, Mrs. Charles's endorsement of pseudo experiments, such as one group designing a diorama inside a condensation chamber, or another group following online directions to create a cloud in a bottle. Additionally, because the students were encouraged to explore any questions they were interested in pursuing, this resulted in the divergence of different groups of students into different lines of research. Divergent explorations did not ultimately feed into the larger purpose of constructing an explanatory account of evaporation and related phenomena. Therefore, our findings reveal that Mrs. Charles's epistemological framing led her to focus on particular aspects of students' ideas—the testability or potential fruitfulness of the ideas—which resulted in iterative cycles of questions, experimentation, observation, new questions over the course of the 15-hour module. The construct of framing allows us to make sense of *why* Mrs. Charles attended to particular aspects of students' ideas, as well as illuminates a direction for progress for a highly responsive teacher that already views students "as 'havers' of ideas and classroom communities as groups that productively entertain these ideas" (Cohen, 2004, p.21).

Discussion

The teacher education literature suggests that really listening to and engaging in students' ideas is a characteristic or skill that takes time for teachers to cultivate (Empson & Jacobs, 2008; Franke, Carpenter, Levi, & Fennema, 2001; Pierson, 2008). In an informal interview with Mrs. Charles, she readily admitted that prior to participation in this professional development project she did not enjoy teaching science, and she described her previous science class as "more traditional" because she followed scripted lessons. During her first year of participation in professional development designed to cultivate more sophisticated practices for facilitating scientific inquiry, Mrs. Charles created a science classroom where the students' ideas took center stage. The students' own reasoning provided a basis for developing and pursuing questions surrounding the 'disappearing' puddle.

When analyzing Mrs. Charles's practice in the classroom, we find that she was highly responsive to students' ideas (Pierson, 2008). Mrs. Charles's classroom interactions and follow-ups demonstrated a variety of clearly responsive moves: she provided space for students to articulate their ideas; she took up student thinking by rephrasing, challenging and building on it; she probed for further clarification; and she shifted the direction of the discussion in ways that addressed student ideas. Simply describing the extent to which Mrs. Charles was responsive, however, does not offer a thorough account of Mrs. Charles's facilitation of scientific inquiry. A closer analysis of her responsiveness revealed a pattern: she tended to respond to ideas that lent themselves to empirical testing and often guided students toward experimentation by challenging how they might "know", "prove", or "test" their ideas. Framing helps make sense of the nuances in Mrs. Charles's responsiveness because it can account for *why* Mrs. Charles chose to take up particular ideas and respond in particular ways. In the case of Mrs. Charles, one component of her epistemological framing—her implicit understanding of how students should address the question, "How do we *know* this proposed idea is valid?" while engaging in scientific inquiry—may have contributed to a very specific kind of responsiveness.

This analysis of Mrs. Charles's practice helps us think about what progress for her might entail. Although Mrs. Charles frequently offered glowing testimonials about what her students were doing as a result of her pedagogical changes, Mrs. Charles expressed a concern during a debriefing session near the end of the module implementation. Prior to class she had created posters summarizing the students' questions and explorations throughout the module; however, she had trouble recording what they had *accomplished* or where they had "*arrived*". Considering this dissatisfaction in terms of Mrs. Charles's framing of scientific inquiry provides insight into how to address her concern and also illuminates a potential path for teacher change. While Mrs. Charles skillfully helped students develop and investigate questions, her framing of science as empirical investigation may have limited her ability to recognize opportunities for other components of scientific inquiry. An alternate framing of scientific inquiry as theory construction *and* experimentation may result in Mrs. Charles modifying the ways in which she is responsive. For example, with this expanded framing of inquiry we may see Mrs. Charles lead students in synthesizing their observations in pursuit of a theoretical model of evaporation. While Mrs. Charles encouraged each group to share out the results of their experiments, these findings were not woven back into a collective explanation for evaporation and the water cycle. Instead, the students' empirical findings were sufficient to suggest whether or not a given variable affects the process of evaporation and became the endpoint of that exploration. Mrs. Charles's comments suggest that *she* sees this endpoint as partially inadequate and unsatisfying. Indeed, there is great potential in what Mrs. Charles has already been able to establish in her classroom. Empirical investigation *is* an appropriate way for students to address questions and resolve competing ideas in science. Even the organization of Mrs. Charles's class, where various groups of students pursued different but related topics of investigation, can be a productive model of scientific collaboration and an appropriate means of arriving at scientific knowledge (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993). By building on Mrs. Charles's existing framing of science, we can help her expand her notion of inquiry to include the coordination of evidence with theory construction, and potentially satisfy her desire to help the students "arrive" at shared explanations for phenomena.

This study is taken from a larger project aimed at, in part, characterizing teacher progress in facilitating scientific inquiry. The construct of *teacher learning progressions* (Schwarz et al., 2009; Thompson, Braaten & Windschitl, 2009), can document how teachers fundamentally alter their view of what can and should take place in the science classroom, and how to hear and develop the beginnings of science in children's thinking. Instead of postulating a progression informed only by data on novice "starting" points and expert "end" points, our larger project attempts to follow the journey of multiple teachers participating in intensive, long-term professional development. Our case study of Mrs. Charles provides a small vignette in that larger story of change. This account of Mrs. Charles's first year can inform how we conceptualize progress and influence what we do during future professional development. For a teacher that easily adopts a student-centered stance in the classroom and is often responsive to student ideas—at least for use in experimentation—defining a learning progression involves more than an analysis of moment-by-moment responsiveness. Understanding Mrs. Charles's epistemological framing of scientific inquiry in the classroom helps illuminate a direction for progress for her, where we can honor and build on what she has already successfully been doing with students.

Endnotes

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(2) Adapted from Glaser & Strauss' (1967) constant comparison method.

References

Abd-El-Khalick, F., Bell, R. L. & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417–436.

Abd-El-Khalick, F. & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education*, *22*(7), 665–701.

Brown, A. L., Ash, D., Rutherford, M., Nakagawa, K., Gordon, A. & Campione, J. C. (1993). Distributed expertise in the classroom. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 188–228). Cambridge, U. K.: Cambridge University Press.

Chinn, C. A. & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218.

Clement, J. (2000). Analysis of clinical interviews: Foundations and model viability. In R. Lesh & A. Kelly (Eds.), *Handbook of research methodologies for science and mathematics education* (pp. 341-385). Hillsdale, NJ: Lawrence Erlbaum.

Cohen, S. (2004). *Teachers' Professional Development and the Elementary Mathematics Classroom: Bringing Understandings to Light*. Mahwah, NJ: Routledge.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, *10*(2 & 3), 105–225.

Duschl, R. A., Schweingruber, H. A. & Shouse, A. W., (Eds). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, D.C.: National Academies Press.
Empson, S. B. & Jacobs, V. R. (2008). Learning to listen to children's mathematics. In D. Tirosh and T. Wood (Eds.), *Tools and processes in mathematics teacher education* (pp. 257–281). Rotterdam, NL: Sense Publishers.
Franke, M. L., Carpenter, T. P., Levi, L. & Fennema, E. (2001). Capturing teachers' generative change: A follow-up study of professional development in mathematics. *American Educational Research Journal*, *38*(3), 653–689.
Glaser, B. G. & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine Publishing Company.
Goffman, E. (1986). *Frame Analysis: An essay on the organization of experience*. New York: Northeastern University Press.
Hammer, D., Elby, A., Scherr, R. & Redish, E. (2005). Resources, framing, and transfer. In J. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 89–119). Greenwich, CT: Information Age Publishing.
Hammer, D., Russ, R., Mikeska, J. & Scherr, R. E. (2008). Identifying inquiry and conceptualizing students' abilities. In R. A. Duschl and R. E. Grandy (Eds.). *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 138–156). Rotterdam, NL: Sense Publishers.
Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, *36*(8), 916–929.
Levin, D. M. (2008). *What secondary science teachers pay attention to in the classroom: Situating teaching in institutional and social systems.* Unpublished doctoral dissertation, University of Maryland at College Park.
Louca, L., Elby, A., Hammer, D. & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*(1), 57–68.
McComas, W. F. (1998). The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The nature of science in science education: Rationale and strategies* (pp. 53-70). Dordrecht, NL: Kluwer.
Metz, K. E. (1995). Reassessment of developmental constraints on children's science instruction. *Review of Educational Research*, *65*(2), 93–127.
National Research Council (1996). *National science education standards*. Washington, D.C.: National Academy Press.
Pierson, J. (2008). The relationship between patterns of classroom discourse and mathematics learning. Unpublished doctoral dissertation, The University of Texas at Austin, 2008.
Russ, R., Scherr, R., Hammer, D. & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education*, *92*(3), 499–525.
Schwarz, C. V., Reiser, B. J., Davis, E., Kenyon, L., Acher, A., Fortus, D., Shwartz, Y., Hug, B. & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632-654.
Sherin, M. G. & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education*, *60*(1), 20–37.
Sikorski, T., Winters, V., and Hammer, D. (2009, June). *Defining learning progressions for scientific inquiry.* Paper presented at the Learning Progressions in Science (LeaPS) Conference, Iowa City, IA.
Tannen, D. (1993). *Framing in discourse*. New York: Oxford University Press.
Thompson, J., Braaten, M. & Windschitl, M. (2009, June). *Learning progressions as vision tools for advancing teachers' pedagogical performance*. Paper presented at the Learning Progressions in Science (LeaPS) Conference, Iowa City, IA.
Tytler, R. & Peterson, S. (2004). From try it and see to strategic exploration: Characterizing young children's scientific reasoning. *Journal of Research in Science Teaching*, *41*(1), 94–118.
Windschitl, M. (2004). Folk theories of "inquiry": How preservice teachers reproduce the discourse and practices of an atheoretical scientific method. *Journal of Research in Science Teaching*, *41*(5), 481–512.

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